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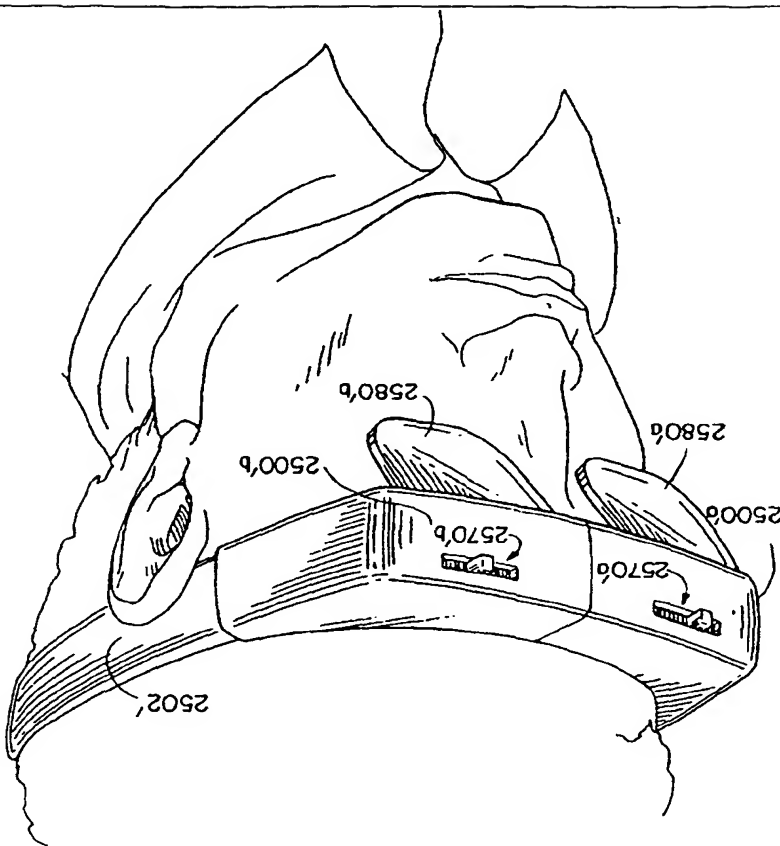
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(57) Abstract

A head-mounted display system displays information via a matrix display element mounted within a housing that is positioned relative to at least one eye of a user. The display is connected to a video or information source such that the user can view information or images shown on the display. The display can be mounted to a frame so that the user can move the display in and out of the user's field of view.



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HEAD-MOUNTED DISPLAY SYSTEM

Background of the Invention

Head mounted display systems have been developed for a number of different applications including use by aircraft pilots and for simulation such as virtual imaging. Head mounted displays are generally limited by their resolution and by their size and weight. Existing displays have relatively low resolution, and because of the size and weight of available systems, these displays are often positioned at the relatively large distance from the eye. Of particular importance, is the desirability of keeping the center of gravity of the display from extending upward and forward from the center of gravity of the head and neck of the wearer, where it will place a large torque on the wearer's neck and may bump into other instruments during use.

There is a continuing need to present images to the wearer of a helmet mounted display in high-resolution format similar to that of a computer monitor. The display needs to be as non-intrusive as possible, leading to the need for lightweight and compact system. Existing head mounted displays have used analog cathode ray tube ("CRT") devices mounted above or to the side of the user's head which project an image onto a surface or visor mounted in front of the user's eyes. Often these displays utilize helmets which incorporate earphones into the helmet. Other head mounted display devices have contemplated the use of liquid crystal devices that could be mounted above or to the side of the user's head and employ reflective optics to direct an image within the field of view of the user.

Summary of the Invention

The present invention relates generally to systems and methods for mounting display and electronic systems on the human body for numerous applications including commercial, industrial and entertainment purposes. Due to the development of small, light weight, high resolution matrix displays, the use of these systems for head mounted and body mounted applications is expected to increase. The use of transferred thin film techniques and/or thin film single crystal silicon material to produce small, high resolution active matrix electronic displays is highly suited for the manufacture of head or body mounted displays is described in U.S. Patent Nos. 5,206,749 (issued April 27, 1993), 5,228,325 (issued November 2, 1993), and 5,300,788 (issued April 5, 1994), the entire contents of these patents being incorporated herein by reference.

Depending on the particular application, it is desirable to use either monocular or binocular systems for head mounted displays. For monocular systems, preferred embodiments have a single display and associated optics in a housing that can be positioned at the center of the field of view of either of the user's eyes and can be moved partially or completely out of the user's field of view. Both monocular and binocular systems can be used with any video source. A preferred embodiment of the monocular system can be mounted to a frame with a hinge so that it can rotate in a vertical plane to a position above the field of view of the user. The frame can be secured to a support that holds the display on the head of the user. The frame can also house the wiring harness for the display as well as other communications systems described hereinafter.

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A particular embodiment, uses either of the
 5 mounted computer system and a user interface. The
 computer and associated electronic components used to
 load programs, load and store data and communicate or
 network with other systems by wire or wireless
 operation can be mounted on the head-piece, or in other
 embodiments, on the chest, back, arms or around the
 waist of the user. The user interface can be a
 10 standard (ISO) keyboard, a collapsible keyboard in
 standard or non-standard format, a voice activated
 system a pen, a joystick, a trackball, a touch pad, or
 a virtual keyboard using motion sensitive gloves, or
 other suitable means depending upon the particular
 15 embodiment and application.
 In accordance with a preferred embodiment of a
 binocular head mounted display, the system can include
 a housing in which a pair of matrix display elements
 are secured. These display elements are of a
 20 sufficiently light-weight and compact nature that the
 housing can be mounted onto the head of a user with a
 pair of hinge mounted arms or support elements that can
 be rotated relative to the housing from a closed
 25 position to an open position. When in the open
 position the arms extend about the opposite side of the
 user's head and serve to position audio transducers
 mounted on the arms into proximity with the ears of the
 user. The arms can also be double hinged in which each
 30 arm is folded once about its mid-point and then rotated
 about the hinge on each side of the housing to assume
 the closed position.
 System electronics and manually adjustable
 controls can be positioned within the housing or the
 35 rotating arms, or on bands extending above or behind
 the head of the user. Positioning of the electronics

and controls within the arms or bands permits a more desirable distribution of weight evenly about the sides or top of the user's head.

The inter-pupillary distance between the two displays can be adjusted such as by the use of a gear driven cam assembly mounted within the housing. Centering of both monocular and binocular displays within the field of view of one or both eyes can thus be accomplished manually, or alternatively by motorized gears or cams. Motors can also be incorporated into the support structure to move the display into, and out of, the user's field of view.

The direct view display can be a transmission type display with the light source directly adjacent the light valve active matrix and mounted within the display device. The transmission type display can, in a preferred embodiment, also receive light directly from the user's environment so that the display overlays an image over the users existing field of view.

Alternatively, the display can be an emission type device such as an active matrix electroluminescent display or an active matrix of light emitting diodes (LEDs), or transmissive passive matrix display or a reflective display.

In various alternative embodiments, a head mounted display can be provided for use with a headband where a molded plastic visor serves as a frame for mounting the electronic display and houses the display wiring harness. An audio system can be mounted on various types of head and body mounted displays described herein, including the headband, the monocular and binocular systems. The audio system can be linked to a computer system, with a network, with connection by

35 color. The displays used herein can be monochrome or
 mounted.
 glasses, visor or frame on which the display is
 level with cause the display to detach from the
 30 so that impacts on the display above a threshold force
 display can be secured with a breakaway mounting device
 safety glasses or other protective components, the
 visor in front of the user's eyes. When used with
 headgear can include transparent safety glasses or
 25 In other alternative embodiments, the protective
 display in front of either eye.
 second horizontal track so that the user can center the
 displays. The monocular system can be placed on a
 monocular system or a binocular system using two
 20 the field of view of the user. This system can be a
 from a retracted position to a viewing position within
 a first track to permit the user to move the display
 mounted on or within the helmet. The frame can include
 one ear of the user. Alternatively, the frame can be
 15 receptacle on that portion of the headpiece adjacent
 securing the frame to the headpiece visor or a
 mounted to the rigid headpiece by clipping or otherwise
 using several alternative devices. The frame can be
 on a frame which can be secured to the user's head
 10 work in combination with an electronic display mounted
 objects. The protective headgear is dimensioned to
 the head of the user to prevent injury from falling
 system includes a rigid protective headpieces covering
 For embodiments including hardhats and helmets, the
 5 for a number of commercial and industrial applications.
 headgear such as safety glasses, hardhats and helmets
 A preferred embodiment provides protective
 sources including radio or television transmitters.
 wire, fiberoptic or wireless systems, or to other audio

having at least 300,000 pixels and preferably over 1,000,000 pixels can be fabricated using methods described in U.S. Patent Application Serial No. 07/944,207 filed September 11, 1992, the teachings of which are incorporated herein by reference.

Brief Description of the Drawings

The above and other features of the invention, including various novel details of construction and combinations of parts, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular head and/or body mounted display systems embodying the invention is shown by way of illustration only and not as a limitation of the invention. The principles and features of this invention may be employed in varied and numerous embodiments without departing from the scope of the invention.

FIG. 1 is a rear perspective view of a preferred embodiment of the invention.

FIG. 2 is a perspective view of a preferred embodiment of a wiring harness.

FIG. 3 is a top plan view of the preferred embodiment of FIG. 1 showing the placement of the wiring harness of FIG. 2.

FIG. 4 is an exploded view of an optical assembly for use in a transmissive display system.

FIG. 5 is an exploded view of a preferred embodiment of an optical assembly for use in an emissive display system.

FIG. 6 is a top plan view showing the embodiment of FIG. 1 in a stowed position.

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- FIG. 7 is an exploded perspective view of a preferred embodiment of cam assembly for the pivot point 39 of FIG. 6.
- FIGS. 8A-8B are partial perspective views of another preferred embodiment for storing the stems 30 of FIG. 1.
- FIG. 9 is a perspective view of an alternative embodiment of the invention.
- FIG. 10 is a front view of an alternative embodiment of the invention.
- FIG. 11 is a top view of an alternative embodiment of the invention.
- FIG. 12 is a side view of an alternative embodiment of the invention.
- FIG. 13 is a back view of an alternative embodiment of the invention.
- FIG. 14 is a bottom view of an alternative embodiment of the invention.
- FIG. 15 is a top perspective view of the alternative embodiment in a closed position.
- FIG. 16 is a bottom perspective view of the closed position.
- FIGS. 17A-17B are detailed views of the sliding assembly.
- FIGS. 18A-18B are further detailed views of the spool assembly and cable management system.
- FIG. 19 is a perspective view of an optics module with portions of the housing broken away.
- FIG. 20 is a back-side view of two modules mounted on a rail assembly.
- FIG. 21 is a perspective view of the optics housing.
- FIG. 22 is a cross-sectional side view of the optics.

FIGS. 23A-23B are schematic diagrams illustrating the full down and full up position of the focus adjusting system of FIG. 19.

FIG. 24 is a perspective view of the focus slide and backlight housing of FIG. 19.

FIG. 25 is an alternative embodiment of the optical system for a high resolution display.

FIG. 26 is an exploded view of the eye-piece display and optics of a preferred embodiment of the invention.

FIG. 27 is a perspective view of a collapsible keyboard in accordance with the invention.

FIG. 28 is a perspective view of a collapsed keyboard and head mounted display device.

FIGS. 29A-29B illustrate another preferred embodiment of the collapsible keyboard and head mounted display system.

FIGS. 30A-30C illustrate another preferred embodiment of a collapsible keyboard and head mounted display system in accordance with the invention.

FIG. 31A is a perspective view of a head-mounted computer with a motorized display arm shown detached.

FIG. 31B is an exploded perspective view of the head-mounted computer of FIG. 31A.

FIG. 32A is a perspective view of a head-mounted computer fitted to a wearer.

FIG. 32B is a perspective view of a preferred display arm, such as shown in FIG. 32A.

FIG. 33 is a perspective view of another preferred head-mounted computer.

FIGS. 34A-34D are views of another head-mounted computer in accordance with the present invention.

FIG. 35 is a functional block diagram of a preferred head-mounted computer architecture according to the invention.

FIG. 36 is a functional block diagram of a general purpose head-mounted personal computer.

FIG. 37 is a functional block diagram for a personal firefighter computing system.

FIG. 38 is a functional block diagram of a head-mounted police computer according to the invention.

FIG. 39 is a functional block diagram of a head-mounted computer for use by chemical factory workers.

FIG. 40 is a functional block diagram of a head-mounted nuclear plant computer.

FIG. 41 is a functional block diagram of a head-mounted mining computer.

FIG. 42 is a functional block diagram of a head-mounted military computer.

FIG. 43 is a functional block diagram on a head-mounted space exploration computer.

FIG. 44 is a functional block diagram of a general purpose head-mounted survival computer.

FIG. 45 is a functional block diagram of a head-mounted maintenance computer.

FIGS. 46A-46E are views of a protective head-mounted maintenance computer of FIG. 45 worn by a maintenance worker.

FIGS. 47A-47D illustrate views of a preferred embodiment of a projection type display.

FIG. 48 is a perspective view of another preferred embodiment of the invention.

FIG. 49 is a perspective view of a back-mounted computer and a head-mounted display.

FIG. 50 is a perspective view of a chest-mounted computer according to a preferred embodiment of the invention.

FIG. 51 is a perspective view of a wrist-mounted computer and display apparatus.

FIG. 52A is a perspective view of a person wearing magnifying glasses equipped with a display.

FIG. 52B is a schematic diagram of the optics of FIG. 52A.

FIG. 53 is an exploded perspective view of a display mounted to a pair of safety glasses.

FIG. 54 is a perspective view of a display for industrial applications.

FIG. 55 is a perspective view of a monocular display in accordance with the invention.

FIGS. 56A-56D are perspective views of another head-mounted display apparatus according to the invention.

FIGS. 57A-57H illustrate perspective view of a particular visor mounted preferred display.

FIG. 58A is a perspective view of a wearer equipped with a preferred embodiment of a head-mounted display.

FIG. 58B is a perspective view of the head-mounted display of FIG. 58A.

FIGS. 59A-59F are perspective views of a collapsible display according to a preferred embodiment of the invention.

FIG. 60 is a perspective view of a head-mounted display integrated with a television tuner.

FIGS. 61A-61B are perspective views of another collapsible keyboard.

FIG. 62 is a perspective view of yet another collapsible keyboard.

FIGS. 63A-63H are schematic diagrams of a preferred process flow sequence for fabrication of a color filter.

FIG. 64 is a schematic diagram of a preferred control circuit.

The images are provided by a remote video source 2, which can be a camera, a computer, a receiver, a video cassette player, or any device that can transmit a video signal. The video source 2 may generate of

reference. 30 the teachings of which are both incorporated herein by Patent Publication WO 93/18428, filed March 12, 1992, 07/971,352, filed November 4, 1992 and International provided in U.S. Patent Application Serial No. 25 discussions of head mounted display devices are which is viewed through the user's right eye. Related viewed through the user's left eye and the other of pair of light valve display panels, one of which is electronic digital imaging to form video images on a 20 assembly 100. The head mounted display exploits be worn by a user to view video images via an optical other light-weight housing material and is adapted to mounted display 1 is constructed of plastic or some embodiment of a head mounted display 1. The head 15 FIG. 1 is a rear perspective view of a preferred

Embodiments of the invention Detailed Description of Preferred

image reflective system for a head-mounted display. FIG. 70 is another preferred embodiment for an 10 image reflective system for a head-mounted display. FIG. 69 is another preferred embodiment for an reflective system for a head-mounted display. FIG. 68 is a cross-sectional view of an image projection head-mounted display. 5 FIG. 67 is a perspective view of a binocular display unit of FIG. 65 worn as a monocular by a user. FIG. 66 is a perspective view of the projection head-mounted display shown partially in cross section. FIG. 65 is a schematic diagram of a projection

video signal from data received over a link 9, such as fiber optic cable. In addition, supply voltage is provided to the head mounted display 1 from a power supply 5, which can provide the required supply voltage through the video source 2. The video source 2 can also provide an audio signal. In a particular preferred embodiment of the invention, the video source 2 and the power supply 5 are physically connected to the head mounted display 1 using a connector 3.

10 It should be understood that the head mounted display 1 can be self-contained such that no physical connection to the remote video source 2 or power supply 5 is required. For example, the head mounted display 1 can contain a receiver to receive transmitted video information and translate that received video information to control signals. Such an embodiment is particularly useful for receiving an over-the-air television broadcast. Similarly, the power supply for the head mounted display 1 can be provided by batteries or another power source (e.g., solar cells) that are integrated into the head mounted display 1.

The head mounted display 1 has a central housing body 12 that is formed from a front housing section 10 and a back housing section 20. The front section 10 is preferably formed from an opaque material such as plastic to block external light 99 from the user's eye's. The rear section 20 is also formed from an opaque material but is adapted to permit the user to adjust the optical assembly 100. The front section 10 is used to mount the optical assembly 100 (FIG. 3). In addition to the optical assembly 100, the user can also adjust a nose bridge assembly 24. The nose bridge assembly 24 can be positioned between an extended position (as illustrated) and a retracted position using an actuating button 25. The user can select a

position from a discrete number of detents. In a preferred embodiment of the invention, the actuating button 25 is fastened to one end of a member that slides within a channel of a support member 15. The opposite end of the member is fastened to the nose bridge assembly 24. When in a selected position, the button is registered to a respective detent. The actuating button 25 is pushed to release the button 25 from the detent so that the nose bridge 24 is retracted.

Attached to each side of the head mounted display body 12 is a stem 30 through a respective forward hinge 31. Each stem contains a forward stem section 32, which is coupled to the forward hinge 31 at the proximal end. In a particular preferred embodiment, the forward stem section 32 contains a rear hinge 33 at the distal end and an earphone storage compartment 37 into which earphones 40 are stowed when the stems are folded.

Rearward stem sections 34 are coupled to the forward stem section 32 joints 33 at their proximal ends. The rearward stem sections 34 are adapted to supply earphones for use by the user. The earphones 40 pivot down from a horizontally aligned position for use by the user. When stowed, the earphones 40 are returned to a horizontally aligned position for storage in the earphone storage compartment 37 of the forward stem section 32. The earphones also slide forward and rearward for adjustment by the user. The rear stem sections 34 also contain control knobs 36R, 36L (see also FIG. 2) for adjusting the audio and video features during the operation of the head mounted display 1. The control knobs 36R, 36L are thus coupled to electronic circuitry, which is also stored within the stem sections 30. In a particular preferred embodiment

of the invention, the right rear stem section 34R contains a volume control 36R and the left rear stem section 34L contains a contrast control 36L. Also in a particular preferred embodiment of the invention, the left rear stem section 34L contains a female connector 38 for interfacing with the video source 2 through the male connector 3. Alternatively, an antenna can be provided to receive audio and video signals and other electronic information.

The head mounted display 1 can be used in numerous and varied applications including, but not limited to, commercial audio/video presentations (television, home video), computer and multimedia presentations, hospital operating room use (e.g. orthoscopic surgery), remote camera monitoring, or any other use where private or detailed viewing of a video image is desired. For certain applications, it is desirable that the body 12 of the head mounted display 1 pivot upward like a visor to permit the user to easily alternate viewing the video image and alive scene. An example of such an application is when the head mounted display 1 is worn by a surgeon during orthoscopic, or other, surgery.

FIG. 2 is a rear perspective illustration of the wiring harness enclosed by the head mounted display 1. In a particular preferred embodiment, audio and video information and supply power is provided via a 10-pin male connector 3. The male connector 3 registers to a 10-pin female connector 38. Of these ten pins, seven pins are provided for the display panel power and backlight power, and three pins are provided for audio signals. The seven video signals are provided to a first circuit 210. The contrast control 36L is coupled to the first circuit 210 to permit the user to adjust the contrast of the images displayed on the light valve display panels. In other preferred embodiments, other

video controls (e.g., brightness, image alignment, color adjust, etc.) are provided and coupled to the first circuit 210. The first circuit 210 is coupled to a second circuit 220, which drives the light valve display panels via an N-conductor ribbon cable 310, where the number of conductors N is determined by the type of display panel.

The first circuit 210 also separates the backlight power signals from the light valve display panel

signals and provides those signals to a backlight driver 240 over a 6-conductor ribbon cable 320. In addition to the two backlight driver signals, the 6-conductor ribbon cable 320 carries four audio signals. A left channel signal 321_L, a common signal 321_C, and a right channel signal 321_R are provided on the 6-conductor ribbon cable 320 to the stereo volume control 36R. In a particular preferred embodiment, the backlight driver 240 and the stereo volume control 36R are disposed within the opposite stem 30 from the circuit 210.

The stereo volume control 36R permits the user to alter the gain of the signals in the right and left earphones 40R, 40L. The adjusted right signal 321_R is provided to the right earphone 40R and the adjusted left channel signal 321_L is carried by the 6-conductor ribbon cable 320 back to the left earphone 40L. Both the left and right earphone are also provided with the common signal 321_C. In other preferred embodiments, other audio controls (e.g., stereo balance, tone, etc.) are provided.

The second circuit 220 need not be a discrete device as illustrated. In another preferred embodiment, the second circuit 220 is fabricated with

each display panel, such that each display panel is controlled by a respective control circuit. The backlight driver 240 provides high voltage signals to the optical assembly 100 over signal lines 340. The high voltage signals can be used to drive a backlight for each display panel where a transmissive display panel is used. Similarly, the high voltage supply can be used to drive an emissive display panel. In a particular preferred embodiment of the invention, the display panels are of the active matrix liquid crystal display type, which require backlighting. In a preferred embodiment the discrete circuitry 38, 210, 220, 240 are disposed near the rear of the head mounted display 1 to provide for more even weight distribution. A preferred control circuit for driving the active matrix display panel 13 is described in U.S. Patent Application Serial No. 07/971,399, filed November 4, 1992, the teachings of which are incorporated herein by reference. In another preferred embodiment, the display panels are of the passive matrix liquid crystal display type. A control circuit for driving the passive matrix display panel is described in U.S. Patent Application Serial No. 07/971,326, filed November 4, 1992, the teachings of which are incorporated herein by reference. FIG. 3 is a top plan view of the head mounted display 1 taken along section line I-I of FIG. 1. The positioning of the wiring harness 300 is illustrated in phantom. Note that the ribbon cables 310, 320 are routed around the joints 31, 33 to permit folding of the stems 30 into a compact unit for storage. In a preferred embodiment, the rear hinge 33 employs a split cylinder that rotates independent of the joint so the ribbon cable is not visible when the stems are opened or folded.

FIG. 4 is an exploded view of the optical assembly for the head mounted display 1. A mounting frame 110 is adapted to be mounted to the inner surface of the front section 10 of the head mounted display 1. The mounting frame 110 has first and second guide rails 111a, 111b to permit adjustment of the inter-pupil displacement of the light valve display panels. The adjustment of the inter-pupil displacement will be discussed in more detail below.

Mounted to the mounting frame is a backlighting assembly 120 for use in transmissive display systems. The backlighting assembly 120 contains a backlight 124, which is preferably a cold cathode backlight. The backlight 124 is disposed in a white reflector 122, which reflects light from the backlight 124 onto the display panel. In a transmissive color display, the backlighting can be provided by a multicolor sequential backlight where there is a backlight for each primary display color (e.g., red, green, blue) and the backlights are sequentially lit in timing with the switching of the light valve. In another preferred embodiment backlight is provided by direct ambient light 99. Through a light transmissive front housing section 10 and mounting frame 110.

A display holder 130 is positioned on the mounting frame 110 such that the mounting frame rails 111a, 111b are disposed within respective display holder channels 131a, 131b. The display holder 130 contains a display area 134 and an aperture 132 through which light from the backlight 124 passes. The display holder 130 also has a geared rack 135 for use in adjusting the inter-pupil displacement. A viscous damped gear assembly 115 meshes with the geared rack 135 such that rotational motion of the gear assembly 115 causes linear movement of the display holder 130 along the

mounting frame 110. As illustrated, the user adjusts the inter-pupil displacement by sliding the left and right display holders 130 along the mounting frame 110. Alternatively, an axle can extend from the gate 115 to a knob or crank lever, preferably disposed on the forward face of the front section 10 of the display body 12. Indicator marking can also be provided to guide the user.

Although only the left portion of the optical assembly 100 is illustrated in FIG. 3, the right display holder is similar to the left display holder, except that the right display holder is rotated 180° relative to the left display holder. In that alignment, the left display holder gear rack 135L is positioned below the gear assembly 115 and the right display holder gear rack 135R is positioned above the gear assembly 115 as illustrated in FIG. 2. Consequently, the gear assembly simultaneously displaces both the left and right display holders when rotated. In a preferred embodiment of the invention, the inter-pupil displacement is adjustable by the user in a range from about 55mm to about 72mm to provide an aligned left-right image to the user.

Returning to the optics assembly, a display assembly 140 is registered to the display chamber 134. The display assembly contains a translucent plastic light diffuser 142, a liquid crystal display panel 144, and a thin plastic matte black mask 147. The diffuser 142 diffuses light from the backlight 124 that passes through the display holder aperture 132 to provide a light distribution that is sufficiently uniform across the display area 146. The liquid crystal display panel 144 has a display area that is 0.7 inch as measured diagonally. The liquid crystal display panel 144 is

preferably fabricated in accordance with U.S. Patent No. 5,317,236 (issued May 31, 1994), the teachings of which are incorporated herein by reference. The display panel 144 contains connectors to connect to the 20-conductor ribbon cable 310 (FIG. 2). The display assembly 140 is secured in the display holder chamber 134 by an optics holder 150, which is fastened to the display holder 130. The optics holder 150 contains a housing 152 that may be conformable to the users eye to block ambient light and surround a cover glass 154. optional lenses 160 are adaptable to the display holder 150 to, for example, correct the user's near vision.

Although FIG. 4 illustrates a preferred embodiment employing a transmissive display panel, an optical assembly 100' can be adapted to receive an emissive display panel 144', as illustrated in FIG. 5. The emissive display optical assembly 100' differs from the transmissive display optical assembly 100 in the following respects. The emissive embodiment does not use a backlight 120. Thus the display holder 130 does not require an aperture 132 nor is a light diffuser 142 required. Instead, the light is provided by emissive material on the display area 146' that is activated by drive signals. The emissive display panel is preferably fabricated in accordance with the aforementioned U.S. Patent No. 5,300,788.

FIG. 6 is a top plan view of the head mounted display 1 in the folded configuration. In particular, note that the nose bridge assembly 24 has been positioned into the retracted position for storage. In the retracted position, the nose bridge assembly 24 does not interfere with the folding of the stems 30. The hinge points 39 on the forward joints 31 are spring tensioned to facilitate head rotation.

FIG. 7 is an exploded view of a preferred spring cam assembly 390R that is used at the hinge port 39R on the right forward joints 31R. The cam assembly 390R comprises a first cam 391R and a mirror image second cam 392R. The cams 391R, 392R contain an outer section 391Ra, 392Ra that registers to a respective receptacle on the body 12 and an inner section 391Rb, 392Rb that registers to a respective receptacle on the forward stem 32R. The inner cams 391Rb, 392Rb each include a landing 393 that allows for free play before engagement. A compression spring 395 is disposed between spring landings. The cams 391R, 392R compress the spring 395 when rotated together. For the right stem 30R, free play is exhibited for an angular displacement from the folded position, thereafter a variable return force is extended by the spring 395, which tends to secure the head mounted display 1 to the user's head. The compression can be adjusted by an adjustment bolt 396 that meshes with a threaded opening on the outer sections 391a, 392b.

FIGS. 8A-8B are partial views of another preferred stem storage embodiment. The forward stem section 32 is a skeleton frame on which the rear stem section 34 slides for storage. (FIG 8B) Alternatively, the forward stem section 32' can encapsulate the rear stem section 34' when stored.

Other preferred embodiments employ other devices to secure the head mounted display, to the user's head. Such devices include an inflatable bladder 61L, 61R (shown in phantom in FIG. 1), with an associated pump assembly, that is disposed over the user's temple, ear loops 63L, 63R, and a headband 65.

In a preferred embodiment, the head mounted display 1 is formed from injection molded plastic. Particular components, such as the nose bridge support

member 15, are rigid glass filtered molded plastic or a composite laminate. FIG. 9 is a front perspective view of another preferred embodiment of a head mounted display unit 1'. The headband 60 coupled together by a pair of pivot assemblies 70a, 70b are adjustable and flex such that the head mounted display unit 1' can be secured to a user's head. The left side pivot assembly 70a is a mirror assembly 70a, 70b. The right side pivot assembly 70b includes a right speaker assembly 80b that can be positioned over the user's ears. Each of these components will be discussed below in further detail. The visor 50 includes a face plate 52 having a backlight as illustrated in FIG. 4. In another embodiment, emissive display panels are used in the visor 50. The visor is connected to the right pivot assembly 70a by a right visor hinge 53a and to the left pivot assembly 70b by a left visor hinge 53b (FIG. 10). The visor hinges 53a, 53b allow the respective pivot of sight of the user to separate the distance between the visor 70a, 70b to flex laterally relative to the line of sight of the user. This flexion, for example, permits the user to separate the distance between the speaker assemblies 70a, 70b so as to fit the display unit 1' over the user's head. The pivot assemblies 70a, 70b each contain components to displace the visor 50 from the earphones 80a, 80b longitudinally relative to the user's line of sight.

sight. This permits the user to properly adjust the visor for a snug fit. More particularly, longitudinal motion is accomplished by cooperation between a front hinge 71 and a center pivot 75. The front hinge 71 is mated to a respective visor hinge 53 by a pin 71'. The front hinge includes a rail section 72 and the center pivot 75 includes a rail section 74. A center coupler 73 permits the rails 72, 74 to slide relative to one another. As illustrated in FIG. 9, the display unit 1' is shown fully extended in the longitudinal direction. Within the center coupler 73 is a wheel 76 to facilitate relative motion between the opposed rails 72, 74.

The headband 60 is preferably formed of rigid plastic and includes a headpiece 62 having a right side 62a and a left side 62b. In each side of the headpiece 62, are a series of spaced detents 68 to couple to a respective pivot assembly 70a, 70b. Optionally, the headband 60 can include a pad 64, preferably made of a pliable rubber foam to provide a comfortable fit over the user's head.

The pivot assemblies 70a, 70b cooperate to permit the headband 62 to rotate about the center pivots 75a, 75b. In a preferred embodiment of the invention, the headband 60 pivots 360° traverse to the plane of the user's line of sight. As illustrated, the headband 60 is positioned at 90°.

A lateral pivot joint 77 is coupled to the respective pivot joint 75 such that when the headband 60 is positioned at the 90° position, a pivot point (not shown) is positioned parallel to the visor hinges 53 such that the speaker assemblies 80a, 80b can flex laterally. A supporting member 79 is coupled to the lateral hinge 77 via the pivot. The supporting element

79 includes a rail 78, which is mated to the series of detents 68 by a catch 79. The headband 60 can be fixed to positions defined by the detent 68 by moving the headpiece 62 along the rails 78.

5 The speaker assemblies 80 are also coupled to the respective pivot assemblies 70a, 70b. A lobe member 87 is coupled to the supporting element 79 of the pivot assembly 70 by a hinge 79'. Each headphone 80 includes a mounting frame 82 which is connected to the lobe member 87. A speaker component 83 is fixed to the speaker frame 82. A foam pad 84 rests against the user's ear such that the user hears sound from the speaker component 83 through an aperture 85 in the foam padding 84.

15 FIG. 10 is a front view of the head mounted display unit 1' of FIG. 9. The front view more clearly illustrates the capability of swiveling the earpiece 80a, 80b about the respective pivot points 79a', 79b'. Also illustrated are slide tabs 56a, 56b for aligning the display panels (not shown) within the visor 50. More particularly, the slide tabs 56 permit adjustment of the inter-pupillary displacement of the display panels. Furthermore, the slide tabs 56 preferably operate independently of each other such that each display panel can be positioned relative to the respective eye to compensate for off-center vision.

FIG. 11 is a top view of the head mounted display unit 1' of FIG. 9. In particular, the lateral motion about hinge pairs 53-71 and 77-79 are illustrated.

30 FIG. 12 is a left side view of the head mounted display device 1' of FIG. 9. As illustrated, the headpiece 62 is fully retracted. In addition, the visor 50 is partially retracted. A pin connector 404 is mounted in element 75b to provide video and audio

connections to the device. Alternatively, two pin connectors can be used, one on 75b, the second on 75a. FIG. 13 is a rear view of the head mounted display device 1' of FIG. 1. Illustrated are ball joints 75a', 75b' of the respective center pivot 75a, 75b. As illustrated, each back section 54 of the visor 50 includes a right viewer 58a and a left viewer 58b. Each viewer permits the user to view images formed on respective display panels (not shown) disposed within the visor 50. Preferably, the viewers 58a, 58b are positioned within respective recessed cavities 57a, 57b of the back section 54 of the visor 50. The recessed cavities 57a, 57b make the display device 1' eyeglasses compatible. Also illustrated is a nose bridge 59, which is preferably molded into the back section 54. Also shown in the figure are control knobs 86a, 86b protruding through the respective speaker assemblies 80a, 80b. In a particular preferred embodiment, the right control knob 86a controls contrast on the display panels and the left control knob 86b controls speaker volume.

FIG. 14 is a bottom view of the head mounted display unit 1' of FIG. 9. More clearly illustrated are the recessed cavities 57a, 57b of the back section 54 of the visor 50. Furthermore, the configuration of the slide tabs 56a, 56b in a respective slide channel 54a, 54b of the back section 54 is illustrated. Furthermore, the head pad 64 is illustrated as having longitudinal ribs to help maintain the headpiece 64 in place. The hinge between 52a and 71a, and the second hinge between 52b and 71b can be "hidden" as shown in FIG. 14.

Between the closed position and the 90° position there can be a discrete number of a detent for

positioning the headband 60. In a particular preferred embodiment, a detent is provided at the 45° position. Alternatively, a friction bearing surface can be used to rotate the visor relative to the headband to hold the visor in a partially raised position.

FIG. 15 is a front perspective view of the head mounted display device 1' of FIG. 9 in a folded position. FIG. 16 is a bottom perspective view of the display unit 1' of FIG. 15. The unique and novel pivot assemblies 70a, 70b cooperate to allow the display unit 1' to be folded into a compact package. The headpiece 60 is rotated about the center pivots 75a, 75b to the 0° position. The earpiece 80a, 80b are then folded behind the headpiece 60, where the earpiece 80a, 80b lie flat. In a particular preferred embodiment, the supporting elements 79a, 79b contain a spring-loaded pin 79a', 79b' to aid the folding of the earpiece 80a, 80b. The pins 79a', 79b' can be similar to the cam assembly of FIG. 7. The visor is then retracted toward the center pivots 75a, 75b until the display unit 1' is securely packed. From this folded position, the head mounted display unit 1' can be easily packed, carried or otherwise transported. FIG. 15 also shows manual focus adjust elements 400 located on the top of the visor which are described in greater detail below.

FIGS. 17A-17B are detailed views of the light pivot assembly 70a. As illustrated, the rails 72a, 74a lie in tracks 73a', 73a'' of a respective center coupler 73a. A wheel 76a having a pin 76a' through its central axis and fixed at one end to the center coupler 73 is disposed between the opposing rails 72a, 74a. Each opposing rail 72a, 74a has a respective slot 72a', 74a' through which the wheel pin 76a' extends. The wheel 76a is held between slots and contains cable guides as

described below. Also illustrated is a connector 89a on the lobe member 87a for connecting the speaker assembly 80a to the assembly. The connector 89a is an electrical connector carrying audio signals.

The wiring of the device is as follows: The signals and power enter through the back of 75b via a connector. The audio portion then passes through to the earcups with one extending through the headband. The video goes forward through the temple slides via the "spool" or wheel 76a. The pin 76a' is the center axle that allows it to rotate in the hole in 73. The pin 76a' is secured to the wheel 76a. FIG. 18A shows pin 76a' and 74a' (shown in FIG. 18A). The wheel sides, 180° apart. These are what ride in the slots 72a' and 74a' (shown in FIG. 18A). The wheel circumference is not in contact with the rails. As shown in the detailed view of FIG. 18A which shows the wheel 76a held between slots 72a'.

FIG. 18B shows the wheel 76a is also a spool. It serves to control the cable length as the rails are moved fore and aft. The spool 76a is designed to be an assembly using two identical pieces 450, 452. A pair of kidney-shaped elements 454, 456 act as cable guides which control the motion of conductor cable 458 as the rails are moved.

FIG. 19 is a perspective view of an optics module sub-assembly 410 with portions of the housing broken away. Two of these modules 410 are mounted to a triangulated rail system 480 having rods 482a, 482b, 482c and comprise an optics assembly. Each optics module 410 consists of the following: A display 420; a backlight 490; a lens 430; a mirror 432; an optic housing 412a; a focus adjust slide 403; an IPD adjust/cover 406; and a rail slide 488.

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centered horizontally left to right as well as acting
as vertical slide surfaces. The button 403a serves as
the top of the assembly capturing the top on the focus
slide.

FIG. 25 shows the display placed at the focal
length of the lens, thus producing an image of the
display at an apparent distance of infinity to the
viewer. The lens has a small focal length, preferable
about 1 inch. The flat optical element is present to
correct for lateral color separation in the lens. This
element consists of a diffractive optic 434 designed to
compensate for the lateral color in the lens. The
mirror serves to fold the optical path to minimize the
depth of the head mounted device while extending its
height. the mirror is optional to the system and is
present for desired form factor. Two such setups make
up on binocular head mounted display system: one for
each eye. The distance that the displays appear to the
viewer can be adjusted for personal comfort, generally
between 15 feet and infinity. The magnification of the
system is about 10. Other lens systems can be used and
are available from Kaiser Electro-Optics, Inc. of
Carlsbad, California. Such a system is described in
U.S. Patent No. 4,859,031 (issued August 22, 1989), the
teachings of which are incorporated herein by
reference. Such a system 500 is shown in FIG. 26. The
display system 500 includes an active matrix display
502, a polarizing filter 504, a semi-reflective concave
mirror 506, and a cholesteric liquid crystal element
508. The image that is generated by the display 502 is
transmitted through the filter 504, the filter 504 the
semi-reflective concave mirror 506 to the element 508.
The element 508 reflects the image back onto mirror 506
which rotates the light so that, upon reflection back
to element 508, it is transmitted through element 508

to the viewer's eye 509. A lens can be used with this system depending upon the size, resolution, and distance to the viewer's eye of the optical system components and the particular application.

One interface device used in conjunction with the various embodiments of the invention is a collapsible keyboard. Preferred embodiments used in conjunction with the display systems described herein are illustrated in connection with FIGS. 27-30. The term collapsible keyboard, used in connection with the present application, means a keyboard have a plurality of sections which move relative to each other to assume a more compact position for storage or transport in which each section has a plurality of keys activated by a user's fingers. A "standard" keyboard means a keyboard having at least three rows of keys for the numbers 0-9, a fifth row for a space bar, a sixth row for dedicated function keys, a laterally positioned numerical keyboard, and four cursor movement keys. As shown in FIG. 27 a keyboard 900 with a standard key configuration can be collapsed and connected, as shown in FIG. 28, with a head mounted display 902 to form a portable computer system 910. As described in the various distinct embodiments herein, the central programming unit, the memory and various parts can be included with the portable keyboard, or alternatively with the headpiece.

In FIGS. 29A and 29B, another preferred embodiment utilizing a collapsible keyboard 922 with hinged elements 922a, 922b, can be connected to head mounted monocular display 924 to provide portable computer system 920.

FIGS. 30A-30C illustrate another portable computer system mountable within portable case 940 with handle

944. A head mounted monocular display 942 can be stored in case 940 which can have a CD-ROM drive 954. FIG. 31A is a perspective view of a head-mounted computer 510 with a motorized display arm 516 shown detached. The head-mounted computer 510 includes a head band 512 with an electrical socket 514. An arm assembly includes a video display panel at the distal end, which provide a video image to a wearer. The arm assembly includes an electrical plug 515 mated to couple with the socket 514. Preferably, there is one socket 514 on each side of the head band 512. The two sockets 514 are bilaterally symmetrical so the arm assembly plug 515 can be coupled to either socket 514 to facilitate use of the display as either a left or right monocular piece. The coupling provides video signals from the computer to the display panel. The arm 516 is operated by a motor 518 which turns a torque ring 517. By turning the torque ring 517, the motor 518 can move the display panel vertically within the wearer's field of view. FIG. 31B is an exploded perspective view of an alternative head-mounted computer 510. The head band 512 includes a base assembly 512a and a computing assembly 512b. The computing assembly 512b includes a CPU and video board module 522, a disk drive module 524 and at least one expansion module 525. The modules 522, 524, 525 communicate with the CPU over a flexible bus 513. The base assembly 512a includes a battery module 529, which supplies dc power to the computer modules 522, 524, 525. Although only one expansion module 525 is illustrated, it should be understood that multiple expansion modules can be added to the flexible bus 523. The display arm assembly includes an electrical plug 515, mated to couple with a socket 514, on the

head band 512'. The arm 516 is operated by a motor torque ring 517'. By turning the 518' which turns a torque ring 517'. The motor 518' can move the display panel vertically within the wearer's field of view.

FIG. 32A is a perspective view of a head-mounted computer 510' fitted to a wearer. The CPU and video driver are fabricated as an integral part of the head band 512. Expansion modules 525a, 525b, 525c are removable and coupled to the bus 513'. As shown, the wearer 601 is fitted with a monocular display. A display pod 1100 is positioned in the wearer's field of view by a display arm assembly 600. The display arm assembly 600 includes a proximal section 610, a distal section 620, a horizontal support member 630, and a nose piece 650. The distal arm member 620 telescopes from the proximal arm member 610 using a supporting member 612. Also shown is an earplug 603.

FIG. 32B is a perspective view of a preferred display arm, such as shown in FIG. 32A. Illustrated is a socket 514' on a broken away head band 512' and an arm assembly 600. The arm assembly 600 couples to the socket 514' by a matching plug 515'. As illustrated, the arm assembly is a monocular arm assembly having a single display panel. The plug 515' and socket 514' are secured together by thumb screw 605.

The arm assembly has a proximal section 610 fixed to the plug 515' and a distal section 620 that telescopes from the proximal section 610. A supporting beam 612 is fixed to the distal arm section 620 and telescopes out from the proximal arm section 610 to support the distal section 620.

A display pod 1100 encasing the display panel is attached to a horizontal frame 630 by a positioning slide 1105. The horizontal frame 630 is attached to the distal arm section 620. A nose bridge 650 supports

the horizontal frame 630 on the wearer's nose. An eye cup 1102 conforms to the shape of a wearer's eye. Electrical signals from the plug 515' to the display panel are carried over a connecting cable 615.

FIG. 33 is a perspective view of another preferred head-mounted computer 510'', as illustrated, there is a head band 512'', stereo headphones 603A, 603B, a display arm 516 connecting the headband 512'' to a display pod 1100', which includes a display panel. The CPU and video drive circuitry are fabricated as an integral part of the head band 512''. Shown on the head band 512'' are plurality of ports 557 which accept expansion modules. As shown, there is a PMMA interface module coupled to the head band 512''. A PMMA module 558 is inserted into the PMMA interface module 554. Also illustrated are expansion modules 514, an infrared communication sensor 555a and a charge coupled Device (CCD) camera 555b.

FIG. 34A is a partial exploded perspective view of another head-mounted computer 510'', in accordance with the present invention. The head band 512'' includes a CPU, a disk drive 564 and expansion modules 525a, 525b, 525c all interconnected together by a flexible bus 563. Each module 564, 525 connects to the bus 563 by a respective connector 517a.

Also shown in FIG. 34A are earphones 603a, 603b for providing audio information to the wearer. Attached to one of the earphones is a microphone arm 690 having a microphone 559 at its distal end. The earphones 603a, 603b are hinged to the head band 512'' to provide a comfortable fit for the wearer.

A frame assembly 600' is coupled to each end of the head band 512'' by a respective pin 602a, 602b. The pins 602a, 602b allow the frame assembly 600' to be rotated up and over the head band 512''. In that

position, the head-mounted computer 510''' is compactly stored and easy to carry.

The frame assembly 600' includes a pair of distal arms 610a, 610b which are coupled to the head band 512 by the pins 602a, 602b. A horizontal support 630' telescopes out from the proximal arms 610a, 610b and around the forehead of the wearer. At least one display pod 1100' is mounted to the horizontal support 630'. As illustrated, a single display pod 1100' provides for monocular display. The display pod 1100' is preferably slidable along the horizontal frame 630' for use with either the left or right eye of the wearer. The display pod 1100' includes an eye cup 1102'.

FIG. 34B is a side elevation of the head-mounted computer 510''' of FIG. 34A.

FIG. 34C is a perspective view of the head-mounted computer 510''' of FIG. 34A with the frame assembly pivoted. The head-mounted computer 510''' can be worn in this position by a person or it can be stored or carried in this position.

FIG. 34D is a perspective view of the head-mounted computer 510''' of FIG. 34A worn by a wearer. The display pod 1100 is positioned for viewing and the microphone 559 is positioned to receive voice signals. FIG. 35 is a functional block diagram of a preferred head-mounted computer architecture according to the invention. The head-mounted computer 710 includes a CPU 712 having read and write access over the bus 513 (FIG. 31B) to a local data storage device 714, which can be a floppy disk, a hard disk, a CD-ROM or other suitable mass storage devices. The CPU 712 also drives a display driver 716 to form images on the display panel 700 for viewing by the wearer.

Either the head or body mounted platforms can house a memory or modem card 741 conforming to the Personal Computer Memory Card International Association (PCMCIA) standards. These cards are restricted to fit within a rectangular space of about 55mm in width, 85mm in length, and 5mm in depth.

A servo 760 communicates with the CPU 712 to vary the position of the display panel 700 relative to the wearer's eyes. The servo 760 is controlled by the wearer through an input device 718. The servo 760 operates the motor 518 (FIG. 31A) to raise or lower the vertical position of the display panel 700. Thus the display panel 700 can be positioned so the wearer can glance up or down at the image without the display panel 700 interfering with normal vision.

Additionally, the display panel 700 can be stowed outside the field of view.

The CPU 712 also sends and receives data from a communication module 720 for interfacing with the outside world. Preferably, the communication module 720 includes a wireless transducer for transmitting and receiving digital audio, video and data signals. A communication module 720 can also include a cellular telephone connection. The communication module 720 can likewise interface directly with the Plain Old Telephone Service (POTS) for normal voice, facsimile or modem communications. The communication module 720 can include a tuner to receive over-the-air radio and television broadcasts.

The CPU 712 can also receive and process data from an external sensor module 730. The external sensor module 730 receives data signals from sensors 735, which provide data representing the external environment around the wearer. Such sensors are

particularly important where the wearer is encased in protective gear.

When the wearer is clothed in protective gear, an internal sensor module 740 can receive sensor data from sensors 745 within the protective gear. The data from the internal sensors 745 provide information regarding the wearer's local environment. In particular, the internal sensors 745 can warn the wearer of a breach or failure of the protective gear.

10 In addition, the CPU 712 can also receive data from a life sign module 750. The life sign module 750 receives data from probes 755 implanted in or attached to the wearer. The life sign data from the probes 755 provides the CPU 712 with information regarding the wearer's bodily condition so that corrective actions can be taken.

The sensor modules 730, 740, 750 receive data from associated detectors and format the data for transmission over the bus 513 to the CPU 712. The sensor modules can also filter or otherwise preprocess the data before transmitting the preprocessed data to the CPU 712. Thus, each expansion module can contain a microprocessor.

The wearer can control the operation of the CPU 712 through the input device 718. The input device 718 can include a keyboard, a mouse, a joystick, a pen, a track ball, a microphone for voice activated commands, a virtual reality data glove, an eyetracker, or other suitable input devices. A preferred eyetracker is described in U.S. Patent No. 5,331,149 (issued July 19, 1994), the teachings of which are incorporated herein by reference. In a particular preferred embodiment of the invention, the input device 718 is a portable collapsible keyboard. Alternatively, the input device 718 is a wrist-mounted keypad.

As illustrated, the head-mounted computer 710 is a node on a distributed computing network. The head-mounted computer 710 is in communication with a distributed command computer 770 via the communication module 720. The distributed command computer 770 has access to distributed data storage 775 for providing audio, video and data signals to the head-mounted computer. The distributed command computer 770 can also be in communication with a central data storage 785. Such external networks can be particularly adapted to applications of the head-mounted display or may be general purpose distributed data networks.

FIG. 36 is a functional block diagram of a general purpose head-mounted personal computer 710'. The head-mounted personal computer 710' includes a communication module 720' for interfacing with an information exchange 790. The information exchange 790 can interconnect the personal computer 710' with other personal computers or informational networks. The communication module 720' can communicate with the information exchange 790 over a wireless data link, a modem, a facsimile apparatus or a digital data link. The communication module 720' can include one or more of the aforementioned communication mechanisms, as required. The local data storage 714 includes software applications for execution by the CPU 712.

In addition to general purpose computing, the head-mounted computer 710 can be adapted for use in many real world situations. In particular, there are situations where a head-mounted computer 710 is especially advantageous. Such situations typically involve applications where the wearer desires or needs auxiliary sensory input.

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FIG. 37 is a functional block diagram for a personal firefighter in a burning system 710A. At least three pieces of valuable information: (1) where the firefighter is located, (2) the dangers surrounding the firefighter, and (3) how to egress the building in an emergency. In addition, the firefighter is located in the building at all times so that any necessary rescue operation can be expedited. In addition to application software, the firefighter is located in the local data storage module 714. Local data storage where the firefighter is located. The firefighter is in communication with a local fire 720A. Vehicle and data communication module 720A provides wireless coverage area of the firefighter maps and building schematics for the truck 770A. The truck 770A is dispatched outside of its normal operation area. The truck 770A is through the communication module, a commander at the truck 770A or a central firefighter. In addition, the communication module includes a global positioning sensor for accurately determining the position of the firefighter. This information is combined with the building schematics by the CPU 712 to provide the

firefighter and the truck 770A with the firefighter's exact position in the building. In addition, the CPU 712 can calculate and direct the firefighter to all exits from the building. In particular, the firefighter's path into the building can be recorded in the local data storage 714 so the firefighter can be directed out of the building following the path over which the firefighter entered the building. Preferably, the directions for backtracking or otherwise exiting the building are pictorially displayed on the display panel 700 so the firefighter can exit even in low or no visibility situations. While in a burning building, the firefighter can encounter closed doors having flames behind them. To warn the firefighter, the external sensors 735A include an infrared detector. Signals from the infrared detector are provided to the CPU 712 by the external sensor module 730A to warn the firefighter of potential hot spots to avoid. In addition, the infrared sensor preferably permits the firefighter to view the surrounding through heavy smoke. Data from the infrared sensor can also aid the firefighter in located trapped fire victims. External sensors 735A can also include a temperature sensor to provide the firefighter and the truck 770A with temperature readings within the burning building. Furthermore, a carbon monoxide sensor can supply the firefighter with the concentration of carbon monoxide in the burning building. Similarly, a natural gas sensor can warn the firefighter of a danger of explosion before a fire occurs.

In addition, the firefighter may be equipped with protective gear. Sensors 745A within the protective gear provide the firefighter with the temperature within the gear, the amount of oxygen remaining in the

firefighter's oxygen tanks and an indication of battery power remaining in the firefighter's computer 710A. If any of these internal sensors 745A exceed predetermined thresholds, the CPU 712 warns the firefighter to exit the burning building.

FIG. 38 is a functional block diagram of a head-mounted police computer 710B according to the invention. As with firefighters, police officers often act alone and must provide information to others and also receive updated information. In a police computer 710B, it can always be with the police officer to service these information needs.

Local data storage 714 can include city maps, building schematics, suspect rap sheets, and emergency medical information. As with firefighters, information can be exchanged between the police officer, a police car 770B and a police station 780B. The police car 770B stores more general maps and criminal data base in a distributed data storage unit 775B. The police station 780B has access to all maps, building schematics and criminal information, which are stored in a central data storage unit 785B.

A communication module 720B permits the exchange of audio, video and data information between the police officer and the police car 770B and police station 780B. The communication module 720B can also include a GPS so the police officer and others know the exact position of the police officer relative to city maps and building schematics. The police computer 710B can also include an external sensor 735B that provides the police officer with night vision. In addition, a magnetic or optical reader can be coupled to the external sensor module 730B. The reader can read driver licenses or other identification and provide the read information to the police station 780B for

verification and a warrants check. The results are then provided and displayed to the police officer without the police officer having to return to the police car 770B during traffic stops or otherwise. FIG. 39 is a functional block diagram of a head-mounted computer 710C for use by chemical factory workers. In particular, the chemical worker computer 710C is worn by those chemical factory workers exposed to or likely to be exposed to caustic or toxic chemicals or gasses. Local data storage 714 includes plant schematics and instructions to the chemical worker, including emergency medical instructions. The communication module 720C provides an audio, video and data link between the chemical worker and the factory control 770C, which can provide the chemical worker with further building schematics and instructions. The factory 770C can also communicate with corporate headquarters 780C for further guidance. The communication module 720C can also include a GPS to identify the worker's position. The chemical worker computer 710C also includes external sensors 735C for detecting caustic chemicals and toxic gas. Data from the external sensors 735C is provided to the CPU 712 by an external sensor module 730C. The external sensors 735C provide the chemical worker with information regarding dangerous substances in or that may have leaked into the work area. The chemical worker may also be working within protective gear. For example, the chemical worker may be working in a hazardous area such as chemical storage tanks. Accordingly, the computer 710C includes internal sensors for measuring the remaining oxygen in the worker's oxygen tanks and remaining power in the head-mounted computer 710C. Data from the internal

sensors 745C are provided to the CPU 712 by an internal sensor module 740C.

FIG. 40 is a functional block diagram of a head-mounted nuclear plant computer 710D. Nuclear plant workers face dangers similar to those of chemical workers. However, instead of detecting caustics and toxins, the nuclear worker computer 710D has external sensors 735D for measuring radiation levels. The radiation data is provided to the CPU 712 by an external sensor module 730D.

FIG. 41 is a functional block diagram of a head-mounted mining computer 710E. The mining computer 710E is worn by a coal miner or similar workers. External sensors 735E measure methane gas concentration. An external sensor module 730E provides the external sensor data to the CPU 712, which can warn the miner of a methane danger. In addition, an external sensor 735E can be a low-light vision sensor.

The communication module 720E provides an audio, video and data link between the mine control room 770E and the miner. For example, the control room 770E can provide a mine supervisor with real-time production rates so the supervisor can shift miners to make efficient use of equipment and human resources. The communication module 720E can also be used to exchange information with the miners in the event of a mine cave-in.

FIG. 42 is a functional block diagram of a head-mounted military computer 710F. The military computer 710F is preferably adapted to be worn by field soldiers operating in areas of high toxicity, such as a combat station exposed to biological or chemical agents or radiation. The military computer 710F can also be worn by military personnel not exposed to such hazards.

The local data storage 714 stores area maps and emergency medical instructions for use by the soldier. The local data storage 714 can also contain repair instructions for equipment used by the soldier.

A communication module 720F provides a wireless audio, video and data link between the soldier and local command officers 770F. The local command officers 770F are in turn linked to remote command officers 780F. The communication module 720F can also contain a GPS, which provides the soldier and command officers with the soldier's location. Through the communication module 720F, the soldier can also receive real-time updates of enemy troop movements. The communication module 720F can also include an encryption/decryption unit securing communication channels.

An external sensor module 730F provides the CPU 712 with data from external sensors 735F. The external sensors 735F include detectors for detecting toxins, biological agents and radiation. The external sensors 735F can also include a night vision unit. If a hazard is detected, the soldier should be clothed in protective gear.

An internal sensor module 740F provides the CPU 712 with data from internal sensors 745F disposed within the protective gear. The internal sensors 745F provide the soldier with a measure of contaminants entering the protective gear.

FIG. 43 is a functional block diagram on a head-mounted space exploration computer 710G. The space exploration computer 710G is worn by an astronaut while in space or exploring another planet or moon. The space exploration computer 710G is particularly useful for use in constructing structures in outer space, such as in earth orbit or on another world. Because

communications between the Earth and the astronaut may fail, the astronaut needs to have ready access to sufficient information to accomplish the mission independently.

5 The local data storage 714 contains maps, schematics and instructions for use by the astronaut. The maps can be used by the astronaut while exploring other objects. The schematics can be used by the astronaut while constructing structures and repairing equipment.

10 A communication module 720G provides an audio, video and data link between the astronaut and a command ship 770G and ground station command 780G.

An external sensor module 730G provides the CPU 15 712 with data from external sensors 735G. The external sensors 735G can include measuring devices for temperature, pressure and gas content of an atmosphere. The external sensors 735G can also include a position sensor to locate the relative position of an astronaut 20 from a fixed reference data point, such as a landing craft. The position sensor data in combination with the maps from the local data storage 714 can be processed by the CPU 712 to provide instructions to the astronaut to return the astronaut to the landing craft. 25 The external sensors 735G can also include an infrared vision unit and a night vision unit to aid the astronaut in dusty environments and at night.

Because the astronaut typically wears a space suit, an internal sensor module 740G provides the CPU 30 712 with data from internal sensors 745G within the spacesuit. The internal sensors 745G measure the temperature and pressure within the suit. From the internal sensor data, the CPU 712 can regulate the temperature and pressure and detect a breach in the 35 suit. In addition, the internal sensors 745G include a

sensor for measuring the remaining oxygen supply in the tanks. From the oxygen supply data, the CPU 712 calculates the remaining time until the oxygen supply is depleted and warns the astronaut when it is time to return to a safe environment.

5 A life sign module 750G provides the CPU 712 with data from probes 755G. The probes 755G measure the astronaut's body temperature, blood pressure, pulse and respiration rate.

10 FIG. 44 is a functional block diagram of a general purpose head-mounted survival computer 710H. The survival computer 710H facilitates the survival and rescue of a wearer. The survival computer 710H can be integrated into a sea survival suit, an arctic survival suit or be a part of a desert survival pack. Pre-stored in the local data storage 714 are maps and medical instructions.

20 A communication module 720H includes a GPS and emergency communication equipment. The GPS data is combined by the CPU 712 with the maps from the local data storage 714 to determine the ground position of the wearer. The CPU 712 can then calculate a path for the wearer to take to obtain safe shelter. The ground position information is also broadcast over emergency channels by the communication module 720H to a rescue team 770H. Once contact is made with a rescue team 770H, the rescue team 770H can provide additional maps and other information to the wearer over a data link. For use of sea, the communication module 720H can also include a sonar transducer for attracting submarines and ships (e.g., a failure of radio communication).

30 An external sensor module 730H provides the CPU 712 with data from external sensors 735H. The external sensors 735H can include temperature and pressure

detectors. The external sensors 735H can also include a night vision unit.

In the event the wearer is wearing protective gear in a cold environment, an internal sensor module 740H provides the CPU 712 with data from internal sensors 745H within the protective gear. The internal sensors 745H measure the temperature within the gear. The CPU 712 can then regulate the temperature and detect a breach in the gear.

10 A life sign module 750H provides the CPU 712 with data from probes 755H. The probes 755H measure the wearer's body temperature, blood pressure, pulse and respiration rate.

15 FIG. 45 is a functional block diagram of a head-mounted maintenance computer 710I. A maintenance computer 710K is worn by repair and maintenance

personnel. The maintenance computer 710I provides the wearer with access to all relevant repair and maintenance manuals and can include diagnostic sensors integrated with the maintenance computer 710I.

20 FIGS. 46A-46E are views of a head-mounted maintenance computer 710K of FIG. 45 worn by a maintenance worker. The maintenance computer 710K is disposed within the hard hat 800.

25 FIG. 46A is a front view of the protective headpiece used with the maintenance computer 710K of FIG. 45 worn by a maintenance worker. The hard hat 800 includes a blister compartment 810, which is shaped to receive the display pod 1100. As illustrated, the display pod 1100 is positioned for viewing by the maintenance worker. The pod is protected from impact by the visor 811 and blister 810.

FIG. 46B is a side view of the maintenance computer 710K of FIG. 45 partially in cross section. The display pod 1100 is coupled to a housing 635 which

is supported by two horizontal members 632, 634 within the blister compartment 810. The housing 635 is slidable along the supporting members 632, 634 to position the display pod 1100 horizontally within the worker's field of view. The display pod 1100 is vertically positioned by a telescoping member 636 that is received by the base 638. In a particular preferred embodiment of the invention, the horizontal and vertical displacement of the display pod 1100 is controlled by a servo 760 (FIG. 45). Shown in FIG. 46C is a side view in which the protective headpiece has a side receptacle 1204 in which the housing 1206 containing the audio circuit, the connector to the display, the earpiece 1208 and microphone 1210 can be inserted. The view of the underside of the helmet is shown in FIG. 46D where the visor 811 has tabs 1202 on both sides so that the monocular display can be mounted at 1200 adjacent to each tab. In the event of an impact to the display pod 1110, it will detach to prevent injury to the user. FIG. 46E is a perspective view of the display pod mounting apparatus of FIG. 46B. Shown more clearly are the supporting members 632, 634 and the housing 635. The display pod 1100 is shown with the telescoping member 636 contracted. Also illustrated is a hinge 639 to allow the worker to pivot the display pod 1100 momentarily out of the field of view. FIGS. 47A-47D illustrated another preferred embodiment of the invention in which a display is mounted above field of view of the user and which projects an image onto a transparent monocular or binocular system in front of the user's eye or eyes. FIG. 47A shows a monocular system 1600 in which a display is positioned in housing 1606 on visor 1605 and projects an image onto lens 1604. The user can also

see through lens 1602 and 1604 to the outside environment. As shown in FIG. 47B, the display is connected by wire or fiber optic cable 1612 to a video source and can be positioned in from of either eye by sliding along rack or rail 1610. The hinge 1614 provides for rotation of lens 1604 against lens 1602. As seen in FIG. 47C, the lens can rotate about hinge 1624 and can be moved along distance 1622. Electronics 1626 for display 1620 can be incorporated into visor 1632 which can rotate about hinge 1630 to position lens 1634, 1638. FIG. 48 is a perspective view of another preferred embodiment of the invention. The wearer is equipped with a helmet 800' adding a blister chamber 810' and a protective goggles 1200 and a breathing apparatus 1300. Although the computer, it should be understood that the head-mounted computer, it should be understood that the computer 710 can be otherwise carried on the wearer's person. For example, the computer 710 can be disposed within a backpack, chestpack or backpack. Other mounting configurations are also meant to be within the scope of the invention. Furthermore, it should be understood that the computer 710 and input device 718 can be remote from the display 700. For example, the person wearing a head-mounted display. The computer 850 is mounted to a harness 852 onto the wearer's back. A data cable 853 from the computer 850 drives the display panel in a display pod 1100 positioned in the wearer's field of view. An audio microphone 559 is mounted to the display pod 1100 for providing local commands to the display pod 1100.

the computer 850 over the data cable 853. Also illustrated is an optional headband 2 for holding the system onto the wearer's head. Preferably, the display pod 1100 can be flipped upward or downward out of the wearer's field of view. The display pod 1100 can also be clipped into a hardhat.

FIG. 50 is a perspective view of a chest-mounted computer according to a preferred embodiment of the invention. A computer 860 is mounted to a wearer's chest by a harness 862. Control of the computer 860 is provided by a roller ball input device 868, which is coupled to the computer 860 by data cable 863. A display housing 867 is extendable from the housing of the computer 860 to permit the wearer to view a display panel. The housing can also have a keypad or a receptacle for a portable or collapsible keyboard (dashed lines).

FIG. 51 is a perspective view of a wrist-mounted computer and display apparatus. The computer body 870 is secured to a wrist by a wristband 872. The computer body includes controls 878 and a display panel 877. A display panel 1000 in the display housing 877 is viewed through a holographic lens 879. FIG. 52A is a perspective view of a person wearing magnifying glasses equipped with a display. The glasses 1905 are secured to the wearer's head by a headband 1902. The glasses 1905 include magnifying lenses 1907 and a hinge 1909 for receiving the display pod 1100. FIG. 52B is a schematic diagram of the optics of FIG. 52A. Illustrated are the display pod 1100 and magnifying glasses 1905. In the display pod 1100 are a display panel 1000, a reflecting mirror 1130 and a viewing lens 1160. The light rays from the display panel 1000 are reflected off from the reflecting mirror

1130 and passed through the lens 1160. Because the glasses 1905 include a magnifying lens 1907, the display pod viewing lens 1160 is a reducing lens. The reducing lens 1160 and the magnifying lens 1907 cooperate to produce a durable image to the wearer. FIG. 53 is a perspective view of a display pod 1100 mounted to a pair of safety glasses with the display pod and safety glass shown exploded. The frame 1915 includes electrical coupling 1913 for interfacing with a display driver and mounting pins 1919. The display pod is coupled to the mounting pins 1919. Safety glass 1917 is positioned between the display pod 1100 and the wearer's eyes to protect the eyes from an impact with the display pod 1100. Preferably, the display pod 1100 is shock resistant. In addition, the mounting pins 1919 are designed to breakaway under stress so that if the display pod 1100 is subjected to an impact, the display pod 1100 will breakaway from the frame 1915.

FIG. 54 is a perspective view of an industrial display. A display housing 1105 is preferably fabricated from impact resistant material. The eyecup 1102 is preferably fabricated from foam or another soft pliable material to protect the user's eye. A protective shade 1102 can be raised or lowered to protect the display panel 1000, the viewing lens 1150 and other internal components from damage.

FIG. 55 is a perspective view of a monocular display. The frame 1925 secures around the back of a wearer's head and earpieces 1921a, 1921b secure the frame 1925 to the user's head. Preferably, the frame 1925 is extendable from the earpieces 1921a, 1921b at joints 1922a, 1922b so the frame 1925 can accommodate various headsizes. The earpieces 1921a, 1921b have a respective socket coupling 1923a, 1923b. A display arm

1926 includes a bilaterally symmetrical plug 1924 that mates with either socket 1923a, 1923b.

The display arm 1926 includes a proximal section 1927 and a distal section 1929. The distal section 1929 can be telescoped away from the proximal section 1927. In addition, a pivot 1928 of the proximal section 1927 permits the display arm 1926 to be rotated upward or downward. A display pod 1200 is coupled to the distal section 1929. The display pod 1200 can be pivoted at various angles relative to the wearer's line of sight.

FIGS. 56A-56C are perspective views of another head-mounted display apparatus according to the invention. FIG. 56A illustrates a headband 1932, a mounting plate 1931 and a brim housing 1930. Pins 1936 on the headband 1932 are inserted into slots 1937 of the mounting plate 1931 to secure the mounting plate to a wearer's head. The brim housing 1930 is mated to tabs 1934 on the mounting plate 1931. A display housing 1300 is slidable along a rail 1933 on the brim housing 1930.

FIG. 56B is a rear perspective view of the brim housing 1930 of FIG. 56A. Shown is a channel 1935 which mates with the tabs 1934 of the mounting plate 1931. This mating process is illustrated in FIG. 56C. The brim housing 1930 is slid along the mounting plate 1931 registering the tabs 1934 with the channel 1935. FIG. 56D shows a more rigid plastic headband 1800 with manual adjustment 1810 to control the size.

FIGS. 57A-57H show detailed perspective views of a particular preferred display of FIG. 56A. The display pod 1300 includes an eyecup 1302 that is fabricated from a pliable material. A first thumb screw 1310 can be turned by a wearer to adjust the vertical position of the display pod 1300 in the wearer's field of view.

A second thumb screw 1320 is turned by the wearer to adjust the distance of the display pod 1300 from the wearer's eye. The display pod 1300 can be tilted up by the wearer out of the field of view. The visor 1930 as shown in FIGS. 57B and 57C can also house the circuit harness for the display which can be connected either through the arm 1332 suspending the pod at hinge 1338 or through cable 1334 as shown in FIG. 57D. A microphone can be connected to visor by connector 1330 and input cable 1336 can be connected on the opposite side.

FIGS. 57E, 57F, 57G and 57H illustrate various rotational positions of display pad including against the user's glasses 1342 at 1340, or against the eye 1343, or retracted above the eye at 1344, or closed against visor 1350 at 1345.

FIG. 58A is a perspective view of a wearer equipped with a preferred embodiment of a head-mounted display. A display pod 1400 is positioned within the wearer's field of view. Dual headbands 1942a, 1942b secure the display pod 1400 to the wearer's head. A connecting cable 1943 carries data signals to the display pod 1400.

FIG. 58B is a perspective view of the head-mounted display of FIG. 58A. The display pod 1400 is coupled to the dual headbands 1942a, 1942b by a telescoping arm assembly 1946 and a pair of ball joints 1945, 1440. The arm assembly 1946 includes a proximal arm section 447 which is coupled to the headbands 1942a, 1942b by a first balljoint 1945, which permits the arm assembly 1946 to be rotated in three dimensions relative to the headbands 1942a, 1942b. The arm assembly 1946 also includes a distal arm segment 1949 which telescopes from the proximal arm segment 1947. The distal arm segment 1949 is coupled to a balljoint 1440 of the

display pod 1400. The second balljoint 1440 permits the display pod 1400 to be positioned in three dimensions relative to the display arm 1946. As illustrated, the display pod 1400 is positioned for viewing by a wearer's right eye. Illustrated in phantom is the positioning of the display pod 1400 for viewing by the wearer's left eye.

FIGS. 59A-59F are perspective views of a collapsible display according to a preferred embodiment of the invention.

FIG. 59A is a perspective view of a collapsible display pod 1500 in its working position. The display pod 1500 includes a top section 1510 and a bottom section 1590 that are rigid. The top section 1510 includes a mounting tab 1502 and a control tab 1504. The display pod 1500 includes a collapsible wall 1550 between the top section 1510 and the bottom section 1590. Also shown is a viewing lens 1560.

FIG. 59B is a schematic diagram of the optical components or the collapsible display pod 1500 of FIG. 59A in the working position. A mirror surface 1525 is joined to a first pivot 1524 and a second pivot 1526. The first pivot 1524 is coupled to the top housing section 1510 by an extension member 1522. The second pivot joint 1526 couples the mirror 1525 to the viewing lens 1560. The viewing lens 1560 is further coupled to a sliding member 1528.

FIG. 59C is a schematic diagram of the optics of FIG. 59D being partially collapsed. As illustrated, the mirror 1525 has been rotated toward the top housing section 1510 by pivoting on the first pivot 1524. The sliding member 1528 has slid toward the first pivot member 1524 along the upper housing segment 1510. Consequently, the second pivot 1526 has pivoted the viewing lens 1560 toward the mirror 1525.

FIG. 59D is a schematic diagram of the optics of Figs. 59B and 59C in the collapsed position. As can be seen, the extension member 1522 is chosen to be of sufficient length so the viewing lens 1560 fits in the space between the folded mirror 1525 and the upper housing segment 1510.

FIG. 59E is a perspective view of the display pod 1500 in the collapsed position. The wall 1550 has folded like an accordion between the upper housing segment 1510 and the lower housing segment 1590. FIG. 59F is a perspective view of the collapsed display pod 1500 mounted to a representative frame 1950.

FIG. 60 is a perspective view of a head-mounted display integrated with a television tuner. The head-mounted display 1960 includes a headband 1962 with stereo headphones 1963a, 1963b. A television or radio receiver 1965 is integrated into the headband 1962. The receiver 1965 includes an antenna 1966 and controls 1967. The controls 1967 can include a tuning control a loudness control and a picture control. A display pod 1600 is connected to the headband 1962 by a display arm 1966. Preferably, a display arm 1966 can be adjusted by the wearer.

Figs. 61A-61B are perspective views of another collapsible keyboard according to the invention which can be used with the various head-mounted and body mounted displays set forth herein. As shown in FIG. 61A, the keyboard 2110 is in its operating position. The keyboard 2110 includes a central body 2116 and two wing members 2112, 2114. When in the operating position 2110, the keys 2115 of the keyboard are in position for use by a user. Also shown are two hinges 2111 and 2113 which permit the keyboard to be folded in the direction of the arrows. As shown in FIG. 61B, the collapsible keyboard of FIG. 61A is in the folded

position. The right wing 2112 folds over the left wing 2114 which is in turn folded over the central body 2116.

FIG. 62 is another foldable keyboard according to the invention. As illustrated, the keyboard 2120 is divided into four segments: a left segment 2122, a left center segment 2124, a right center segment 2126 and a right segment 2128. Each segment includes a plurality of keys 2125. To fold the keyboard, the bottoms of the left center and right center segments 2124, 2126 are folded together at a central hinge 2127. Then the left and right segments 2122, 2128 are folded at hinges 2121, 2123 respectively.

The display panels described herein can generate either monochrome or color display images. Color images can be generated using color filters. Color filters are preferably fabricated within the display panel and registered to the pixels.

FIGS. 63A-63H are schematic diagrams of a preferred process flow sequence for fabrication of a color filter system for a transferred film active matrix display. This process provides a compact, high resolution, high speed color display that fits within a small volume suited for head-mounted displays. In particular, the color filters are polyimide color filters. More specifically, the color filter illustrated is a PIC Green 02 filter available from Brewer Science, Inc. of Rolla, Missouri.

As shown in FIG. 63A, a pixel element 2010 having an electrode 2012 and a transistor 2014 is formed on a semiconductor layer 2015, preferably a thin film single crystal silicon having a silicon-on-insulator structure, but optionally being formed with a polycrystalline or amorphous silicon material for applications having greater tolerances for speed and

resolution. The single crystal silicon film is particularly well suited for small, high resolution, high speed displays used in head-mounted computer system applications. An optional nitride layer 2020 can be formed over the pixel element 2011, as shown in FIG. 63B. An optional adhesion promoter (not shown) can next be coated and baked onto the nitride layer 2020. In a preferred embodiment, however, an adhesion promoter is not used.

10 A layer of polyimide, such as PIC Green 02 is spun on over the circuit at a speed of 1,000 rpm for 90 seconds. The resulting structure is shown in FIG. 63C. The polyimide layer 2030 is about 1 to 5 microns thick. In a preferred embodiment, the polyimide layer 2030 is about 2 microns thick. The structure is then subjected to a solvent removal bake at 120°C for 60 seconds on a hotplate. It should be noted that a solvent bake is not critical. The structure is then subjected to a second or "beta" bake at 168°C on a hotplate for 90 seconds in vacuum contact. It is critical that the temperature be uniform in the beta bake step because the beta bake defines the develop processing characteristics.

25 As shown in FIG. 63D, a photoresist pattern 2040 is applied to the structure. The positive photoresist is coated, baked and exposed 2050 at twice the normal dosage. The pattern is then developed with a standard fluid developer for 40 seconds. The developer is preferably a metal ion free developer such as Shipely MF-312. The polyimide 2030 will develop with the photoresist. The structure is then rinsed in water and dried with nitrogen or clean compressed air.

30 The photoresist is then removed with a commercially available carbon-based solvent which is

spun onto the structure. The resulting color filter structure 2035 shown in FIG. 63E is then hand baked between 200°C and 260°C for one hour in an oven. In a preferred embodiment, the baked temperature is 230°C.

5 The above process is repeated for the red and the blue color filters to provide a full color liquid crystal display or an electroluminescent display.

There are many alternative color combinations for producing polyimide material used in color filter array fabrication. Properties which may vary with different formulations are: color coordinates, spectral transmission, heat stability, color saturation and light stability. Depending on the application, an appropriate formulation can be chosen to maximize the qualities which are most desirable. Additionally, the thickness of the applied polyimide film can also be varied. In this case the tradeoff is between color saturation and spectral transmission. In the present process, a layer thickness of about 1.4 μm is used on all three colors. If increased transmission is critical, a slightly thinner coating can be used, but this can result in the sacrificing the desired level of color saturation.

25 After the color filter layer (RGB) has been fabricated, it is necessary to encapsulate the colored polyimides with some type of barrier or capping layer 2060. This step shown in FIG. 63F is important for a number of reasons. Dye can leach out of the polyimide causing changes in the actual color of the pixels, cross contamination of adjacent material whether it is adhesive, liquid crystal if the color filter elements are disposed on the liquid crystal side of the active matrix, or another medium. In addition, colored polyimide, especially certain commercially available

types are particularly sensitive to heat and light

degradation. This is an important problem in the case of applications using higher light intensity levels or relatively hot operating environments, but we have

5 discovered that by encapsulating the polymides with a thin film coating such as silicon nitride, followed by mounting to glass with adhesive, not only is the

leaching of the dye eliminated but also the heat and light degradation problem. Other types of barriers as indicated above can also be used to achieve the same effects.

FIG. 63G illustrates the transferred color filter array transferred onto a glass substrate 2064 with an

15 adhesive layer 2062. After transfer, the resulting structure is packaged, is shown in FIG. 63H with the liquid crystal material 2066 and the counterelectrode structure 2068. The resulting color active matrix

display can be mounted in any of the head-mounted display systems described herein and used to provide a

20 full color display, or alternatively, any selected number of colors including a two color display such as green or blue on a dark background as is commonly found in many computer applications displaying text and/or

simple graphics. As display resolutions increase, the demand for real estate may increase such that the electrodes and

transistors are formed in separate layers. The electrode is interconnected to the transistor by an

30 pixel elements having stacked electrodes and interconnect through an insulator layer. This way, transistors can be fabricated in an array of pixels.

An EL stack, for example, employing a white phosphor layer and color filter elements are then fabricated over the electrodes, either by monolithic fabrication

35 or transfer and alignment on a prefabricated EL stack.

Interconnection through the insulator can also be incorporated into a liquid crystal display.

The display panel is controlled by control circuitry which is preferably head-mounted with the display panel. The circuitry can be provided on circuit boards disposed within the head gear or directly on the display panel. Such control circuitry is described in detail in U.S. Patent Application Serial No. 08/106,416, filed August 13, 1993, the teachings of which are incorporated herein by reference.

FIG. 64 is a schematic diagram of a preferred control circuit. Components of this circuit can be incorporated directly in the headset of a head-mounted display, or can be used in a separate body mounted circuit housing as described elsewhere herein. The latter option is highly desirable in applications in which the headset must have minimum weight and volume and still provide portability. A video signal source (not shown) provides video signals to the head-mounted display. The video signal source can be any analog or digital video signal source including a Video Graphics Array (VGA) adaptor, the Apple™ Macintosh™ family of computers, a National Television Systems Committee (NTSC) composite video source, a high-resolution professional display adapter, a Charge-Coupled-Device (CCD), or other similar sources. In a particular preferred embodiment, the active matrix display panel is adapted as a computer-controlled light valve. Horizontal and vertical synchronization signals from the video signal source are provided to a video interface 2410 on data lines 2313 and 2314, respectively. Red-green-blue (RGB) video signal components, if supplied by the video signal source, are provided to an encoder 2440 on respective data lines

2301, 2302, 2303. If discrete color (e.g., RGB) signals are not supplied by the video source (e.g., NTSC composite video signal), then a single encoded video signal 2341 must be supplied by the video source. The appropriate video signal is supplied to a video polarity network 3450 on data line 2441, the operation of which is described in greater detail below.

The active matrix 2390 (shown in phantom) operates as a multi-frequency display device. Typically, video signals from the video signal source will not be synchronized to a fixed frequency. A change in the video mode can change the resolution of the data, measured in pixels. For example, a VGA adaptor generates synchronization signals that vary depending on the particular video mode in which the adaptor is operating. A standard VGA adaptor can generate a vertical synchronization frequency between about 56 and 70 Hz and a horizontal synchronization frequency between about 15 and 35 KHz. For professional display purposes (e.g., CAD/CAM) the vertical and horizontal synchronization frequency can be higher than described. To handle current high resolution display applications, the display device can preferably adapt to vertical synchronization frequencies up to about 100 Hz and horizontal synchronization frequencies up to about 66 KHz. In addition, a change in the video mode can also invert the polarities of the synchronization signals. Consequently, a preferred embodiment of the invention adapts to changes in the synchronization signals caused by changes in the video mode.

The video interface 2410 is used to interface the head-mounted display with the horizontal and vertical synchronization signals from the video signal source. In a preferred embodiment, the video interface 2410 interfaces with a standard VGA display adapter to

display the video image at a horizontal resolution of 640 pixels and a vertical resolution of 480 pixels (640H x 480V). In another preferred embodiment, the display resolution is 1024H x 768V. In yet another preferred embodiment, the display resolution is 2048H x 2048V. The video interface 2410 adjusts to changes in the input synchronization frequencies by detecting polarity, frequency, or phase changes in the input signals.

10 A preferred embodiment of the invention for use with video signals for a VGA adaptor supports 720H x 400V text mode, 640H x 480V graphics mode, 640H x 400V graphics mode and 640H x 350V graphics mode. Table I summarizes video rates and resolutions associated with these supported VGA modes. It will be understood that other video modes having different video rates and resolutions can be supported as well, with minor modifications.

Horizontal and vertical synchronization signals are provided at TTL levels on respective incoming data lines 2313, 2314 from a VGA adapter or similar video source. A control processor 2412 examines the incoming video stream and tracks mode changes, which provide for

Mode	Graphics	Graphics	Graphics	Text
Resolution	640H x 480V	640H x 400V	640H x 350V	720H x 400V
Pixel Rate	25.175 MHZ	25.175 MHZ	25.175 MHZ	28.322 MHZ
Horizontal Rate	31.47 KHz	31.47 KHz	31.47 KHz	31.47 KHz
Vertical Rate	59.94 Hz	70.08 Hz	70.08 Hz	70.08 Hz
Hsync Polarity	Negative	Negative	Positive	Negative
Vsync Polarity	Negative	Positive	Negative	Positive
HORIZONTAL				
Time Pixels	25.42us	640	25.42us	640
Active Scan	0.64us	16	0.64us	16
Front Porch	3.81us	96	3.81us	96
Sync Width	1.91us	48	1.91us	48
Back Porch	1.91us	48	1.91us	48
Back Porch	1.91us	48	1.91us	48
VERTICAL				
Time Lines	12.71ms	400	11.12ms	350
Active Scan	0.35ms	11	0.18ms	37
Front Porch	0.06ms	2	0.06ms	2
Sync Width	1.02ms	32	1.11ms	35
Back Porch	16.68ms	525	14.27ms	449
Total Period				

TYPICAL VGA RATES AND RESOLUTIONS

TABLE I

variable frequency multi-scanning capability. Upon detecting a mode change, the control processor 2412 signals the mode change to a dot clock regenerator 2414. Optionally, the control processor 2412 interprets input signals from a remote control device over a remote signal line 2331 and either controls hardware or provides remote mouse functionality over a mouse signal line 2309 to the computer, as required. Preferably, a non-volatile Editable Erasable Programmable Read-Only Memory (EEROM) is used to store setup and adjustment parameters. The program for the processor is contained within a Erasable Programmable Read-Only Memory (EPROM) which simplifies upgrading the functionality of the program. Most digital logic is contained within Field Programmable Gate Arrays (FPGAs), which are also programmed from the same EPROM. Upgrading the EPROM allows functionality to be changed, added or repaired, all with little manufacturing cost. The dot clock regenerator 2414 provides a pixel data signal on line 2411, a pixel clock signal on line 2413, a frame switch signal on line 2415, a select clock signal on line 2417, and a select data signal on line 2419.

The dot clock regenerator 2414 recreates the pixel dot clock used by a computer to output pixels. The regeneration must be accurately controlled because it is very important to provide a clock that is centered over each pixel and does not drift. Thus, a clock must be recreated that can be used to sample a pixel and move to the next pixel. The dot clock regenerator 2414 includes a phase locked loop (PLL) network and Voltage Controlled Oscillator (VCO), which are responsive to the mode change signal over data line 2416. There is no standard for the frequency of the incoming video

[illegible]

interface 2410 provides a pixel data signal and a pixel clock signal to a data scanner 2420 on respective data lines 2411, 2413. The video interface 2410 also provides a select line data signal and a select line clock signal to select scanners 2430a, 2430b on respective data lines 2417, 2419. Preferred embodiments of the invention supply one or four clocks on each clock signal line 2413, 2417. By supplying four clock signals on each clock signal line 2413, 2417, the circuitry of the scanners 2420, 2430 can be simplified. This is especially important if the scanners 2420, 2430 are fabricated on the SOI structure with the active matrix 2390 and the video interface 2410 is a discrete component. Finally, the video interface 2410 provides a frame switch signal to the video polarity network 2450 on data line 2415.

Encoder 2440 may be a gray-scale encoder or a color encoder. The RGB signal is provided from the pinout connectors on signal lines 2301, 2302, 2303. The encoder converts the RGB signal into a mapped analog signal. A gray-scale encoder employs a colored mapper to convert the RGB signal into a gray-scale equivalent. In a preferred embodiment, each color from the RGB signal is weighted and then summed together to form a gray-scale signal. The gray-scale mapper uses the equation

$$V_o = w_R V_R + w_G V_G + w_B V_B, \quad (1)$$

where V_o is the gray-scale output signal; w_R , w_G , and w_B are the respective weighting for the red, green and blue signals; and V_R , V_G , and V_B are the respective signal strengths for the red, green and blue signals. In a preferred embodiment of the invention, $w_R=0.3$,

$w_G=0.59$ and $w_B=0.11$ to result in a weighting function approximately equal to the human eye's relative response. However, other weighting values can be obtained by changing resistor values in the circuit.

5 If the video source supplies a monochrome signal, that signal is preferably applied at the green input 2302. In addition, other mapping techniques may be employed without affecting the scope of the invention (e.g., digital mapping). A color encoder employs a multiplexer to multiplex the RGB signal into a mixed color equivalent. In a preferred embodiment, the encoder 2440 provides either one of gray-scale or color encoding, as required. The encoded analog signal from either the gray-scale mapper or color encoder is provided to the video polarity network 2450 via an encoder line 2441.

10 In a further embodiment, the video source can provide an NTSC composite video signal on signal line 2423. In an NTSC composite video signal, the RGB signals and the synchronization signals are superposed as a single analog video signal. Because the RGB signals are already encoded in a NTSC composite video signal, no separate encoding is necessary. Instead, the superposed RGB data is extracted from the NTSC composite video signal. The superposed RGB data from an NTSC composite video source is provided to the video polarity network 2450 on line 2441.

20 The video polarity network 2450 generates odd and even video driven signals 2459 from the frame switch data on line 2415 and the analog video signal on line 2441. The video drive signal 2459 is adjusted by a contrast control signal 2351, a back porch clamp signal 2353, a brightness control signal 2355, the liquid crystal reference voltage 2461, and feedback signals

2473, 2483 from a temperature measurer 2470 or light meter 2480. The video polarity network 150 incorporates a video amplifier 2452, bias network 2454, and a video switch 2456.

5 The analog video signal from line 2441 is provided to the video amplifier 2452. The video input 2441 is amplified by an amount determined by the contrast (gain) control voltage 2351 generated by a digital-to-analog (D/A) converter 2350. Because the video input is AC coupled, the DC restore function is done by a back porch clamp (not shown). The brightness (level) control 2355 is the reference voltage for the clamp which is obtained from the D/A converter 2350. The feedback for the clamp is taken from the main video outputs, which closes the loop around the full video path. In a preferred embodiment, this block is implemented by a National Semiconductor LM1201 amplifier, although other suitable amplifiers can be used.

20 One important feature is that there are two complementary outputs from the video amplifier 2452. A normal output is positive-white from a (clamped) level a few volts above ground. An inverted output is negative white from a few volts below the positive supply voltage (12V). These two outputs are inherently in phase, and have the same gain because they are preferably taken from the same output transistor. Alternatively, the amplifier gain can be nonlinear (e.g., gamma functions). The normal and inverted amplifier signals are fed to a bias network 2454.

30 The bias network 2454 is an RC network that biases the two outputs of the video amplified 2452 toward each other. Those outputs can never reach the same voltage, due to the nature of the output stage. But the inputs to the drive amplifiers 2458 should be capable of

crossing over in some cases, to allow a full range of contrast and brightness adjustment. The output signals from the bias network 2454 are fed to the video polarity switch 2456.

To provide the AC component of the required active matrix drive signal, video switches select either the normal or the inverted video signals. These video signals are supplied alternately to an odd drive amplifier, with an even drive amplifier receiving the opposite signal. Preferably, the switches change every video field (every vertical sync). The switch could occur more or less often, as might be desirable for crossstalk or other purposes; a preferred switching rate allows switching every scanline. The switches used are FET-based "T" switches, which provide good isolation and fairly low "on" resistance. A switch is also used to select between the outputs, to always provide a "normal" feedback signal for clamping comparison. The video polarity switch 2456 is synchronized to the frame rate provided over the frame switch line 2415.

In a preferred embodiment, a column inversion technique is used to reduce crosstalk between select lines to reduce or avoid the production of a DC offset voltage. The video switch 2456 provides an alternating opposite polarity for the column pixels. The even column pixels are operated at the opposite polarity of the odd column pixels. The polarities of the column pixels are switched on each sequential frame. For example, on one frame even column pixels operate at a positive polarity and odd column pixels operate at a negative polarity. On the next sequential frame, the switch 2456 switches the polarities of the odd and even columns. As a result, the even column pixels operate at a negative polarity and the odd column pixels operate at a positive polarity. The odd column

polarity is provided to the active matrix on line 2459b and the even column polarity is provided to the active matrix on line 2459a.
 Another preferred embodiment of the invention uses a frame inversion technique instead of column inversion. Using frame inversion, each column during any one frame has the same polarity. On alternating frames, as clocked by the frame switch 2415, the polarity of each column is reversed. In that way, the polarity of the entire active matrix 2390 is inverted on each successive frame. Note that this frame inversion embodiment would not require the use of distinct odd and even data registers 2422.
 The data scanner 2420 provides for double storage of pixel data. The data scanner 2420 interfaces with the pixel data signal on line 2411 and the pixel clock signal on line 2413 via interface component 2425. The data scanner 2420 uses an odd shift register array 2422a and an even shift register array 2422b to store data for each scan. The odd shift register array 2422a stores data to odd column pixels and the even shift register array 2422b stores data to even column pixels. A transmission gate 2426 transmits pixel actuation signals to the active matrix 2390. The transmission gate 2426 is partitioned into odd column gate 2428a and even column gate 2428b, which are registered to respective columns of the data scanner shift registers 2422a, 2422b. A serial data stream of a video drive signal is provided to the odd and even column pixels on respective signal lines 2459a, 2459b. An appropriate signal level is transmitted by the transmission gate 2426 to the correct pixel as triggered by the output from the shift registers 2422.
 To reduce signal loss across the active matrix, the select lines are driven from both sides by select

scanners 2430. As viewed in FIG. 64, left select scanner 2430a and right select scanner 2430b are connected to the select data line 2419 and the select clock line 2417. The left select scanner 2430a provides a select line signal at the end of the select line nearest the lowest-valued pixel column (C_1) and right select scanner 2430b provides a select line signal at the end of the select line nearest the highest-valued pixel column (C_N). Thus, an identical select line signal is supplied at both ends of the select line.

In a further preferred embodiment, at least one sensor 2392, 2394 is integrated into the active matrix 2390 for gray-scale adjustments. The sensor may be a temperature diode, a photo transistor or diode, or combinations thereof. A preferred embodiment employs at least one temperature sensor 2392 and at least one light sensor 2394. The signals from the sensors provide feedback signals, to the video polarity network 2450, which adjusts the gray-scale signal strength.

In a preferred embodiment, the sensors 2392, 2394 are uniformly distributed throughout the active matrix. For example, each pixel element, or a selected group of pixel elements can have an associated sensor 2392, 2394. The sensor to pixel ratio need not be one-to-one however. In another material embodiment, the sensors 2392, 2394 are distributed around the perimeter of the active matrix.

FIG. 65 is a schematic diagram of a projection head-mounted display 2500 shown partially in cross section. Shown is a housing 2510 separated from a user's head by a foam pad 2515. The housing 2510 is preferably fabricated from plastic but other lightweight materials can also be used. A backlight

2520 projects light through a display panel 2530 to form an image. The image is operated on by an optics system 2550 similar to that described in the aforementioned U.S. Patent No. 4,859,031. Illustrated is a concave partially reflective mirror 2512 and cholesteric liquid crystal (CLC) element 2554.

The image is circularly polarized by the display panel 2530 and is transmitted through the concave mirror 2512. The image is then reflected by the CLC element 2554 back toward the concave mirror 2512, which reverses the polarization and reflects the image back toward the CLC element 2554. The CLC element 2554 now transmits the reverse polarized image. The light may be reflected once or multiple times from the concave mirror 2512 of correctly orient the polarization of the image for transmission through the CLC element 2554. The image is then reflected from a viewing surface 2580 toward the user's eyes. The viewing surface 2580 is preferably a partially transmissive mirror that overlays the generated image over the images of real objects in the wearer's field of view.

Circuitry for driving the display panel 2530 is located both on the display panel 2530 and on a printed circuit board 2560 disposed within the housing 2510. Alternatively, circuit elements may be located elsewhere on the headpiece or on the user's body. A flexible flat cable 2565 interconnects the circuit board 2560 with the display 2530. A focus adjust mechanism 2570 is provided for use by the wearer. The display panel 2530 can be an active matrix liquid crystal display as described in greater detail above.

FIG. 66 is a perspective view of the projection display unit of FIG. 65 worn as a monocle by a user. The display unit 2500 is secured to the wearer's head by a headband 2502 or by other head mounting support

systems described elsewhere herein, including hardhats and face protectors. The focus adjust mechanism 2570 is a knob that can be turned by the wearer. When not in use, the partially transmissive mirror 2580 can be folded out of position into the display unit 2500. FIG. 67 is a perspective view of a binocular reflective head-mounted display. As illustrated, two display units 2500a', 2500b' are coupled together and fastened to the wearer's head by a support such as headband 2502'. The focus adjust mechanisms 2570a', 2570b' are slide mechanisms. Each eye has a corresponding partially transmissive mirror 2580a', 2580b'.

FIGS. 68-70 illustrate other preferred embodiments of a direct-view display system. Light from a display device 2500 is represented by light ray 2615. The light ray 2615 from the display 2500 can be combined with ambient light 2690 before becoming incident on a viewer's eye 2600. Thus, the image created by the display device 2500 appears to the viewer to float in the viewer's field of vision.

There are various means of combining the display image 2615 with the ambient image 2690, which will now be described. FIG. 68 illustrates a preferred embodiment of the invention using a prism 2710 to combine the images. The hypotenuse of the prism can be coated with a partial reflector or electrochromatic material 2712 to attenuate ambient light 2690. FIG. 69 illustrates a preferred embodiment of the invention using a lenticular structure 2720 as an image combiner. The gradings are spaced such that the eye 2600 cannot distinguish lines in the structure 2620. In a preferred embodiment, the grating density is greater than or equal to 150 per inch and can be color selective so as to redirect only a certain color or

colors that will be easily viewed by the user relative to the ambient light. FIG. 70 is similar to the lenticular structure in FIG. 69 except that a Fresnel lenticular structure 2730 is used. In both lenticular structures 2720, 2730, the flat surface 2722, 2732 can be coated with a partial reflector or electrochromatic material. In either of FIGS. 68-70, the display system 2500 is mounted adjacent to the viewer's head. In a preferred embodiment of the invention, the display device 2500 can alternatively be mounted adjacent to the sides of the viewer's head.

Equivalents

Those skilled in the art will know, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. These and all other equivalents are intended to be encompassed by the following claims.

1. A head mounted display system comprising:
a support frame for positioning on a user's head; and
a display module having a display panel and an optical system for generating a displayable image, the module being mounted on the support frame.
2. 10 The head mounted display system of claim 1 wherein display panel comprises an active matrix liquid crystal display.
3. The head mounted display system of claim 1 further comprising a second display module to form a binocular display.
4. The head mounted display system of claim 2 wherein the active matrix display is positioned to direct an image onto the user's left eye and further comprising a second active matrix display mounted on the support frame such that the second active matrix display directs light onto the user's right eye.
5. The head mounted display system of claim 1 further comprising a computer connected to the display panel.
6. The head mounted display system of claim 1 wherein the display panel comprises a color display.

Claims

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7. The head mounted display system of claim 1 wherein the display panel comprises an electroluminescent display.
8. The head mounted display system of claim 5 wherein the computer is mounted on the body of the display user with a harness.
9. The head mounted display system of claim 1 wherein the support frame comprises a protective head piece.
10. The head mounted display system of claim 9 wherein the head piece comprises a transparent faceplate.
11. The head mounted system of claim 1 further comprising:
a reflective surface to view an image such that the display projects an image on the surface in an optical path, the reflective surface having a diffraction grating.
12. The system of claim 1 wherein the module is rotatably mounted to the frame.
13. 20 The system of claim 11 in which the display is a flat panel display formed of a back panel with an active matrix array formed with Si thin film transistors transferred onto said back panel, a front panel and a liquid crystal material enclosed between the front and back panels.
14. The head mounted display system of claim 1 comprising a slide that supports the module before either eye of the user.

15. The system of claim 5 further comprising a keyboard.
16. The system of claim 15 wherein the keyboard is collapsible.
- 5 17. The system of claim 1 wherein the module can be moved from a retracted position within a housing to a viewing position.
18. The system of claim 1 further comprising a video circuit.
- 10 19. The system of claim 1 further comprising a sensor.
20. The system of claim 1 further comprising a modem for receiving a display.

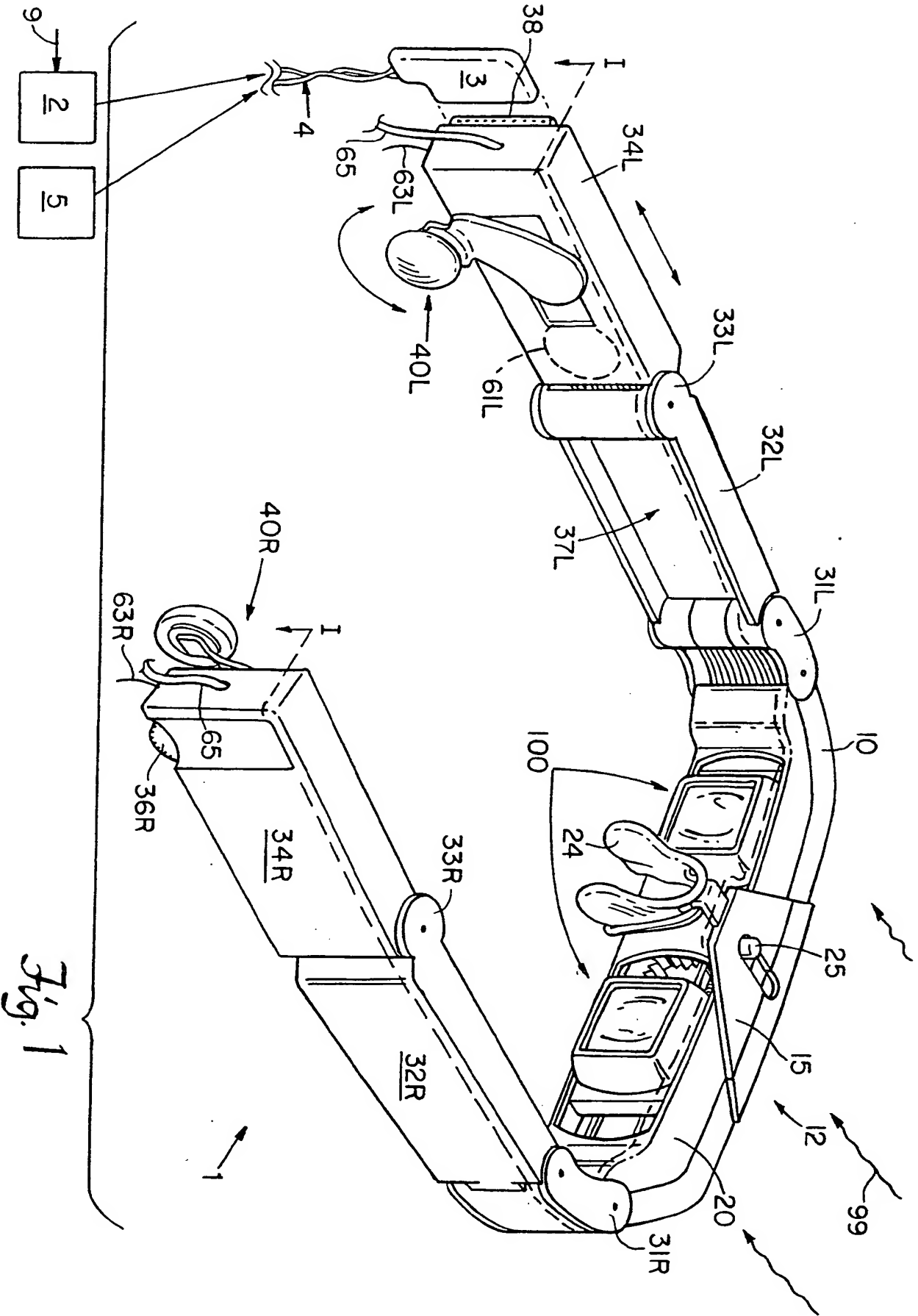


Fig. 1

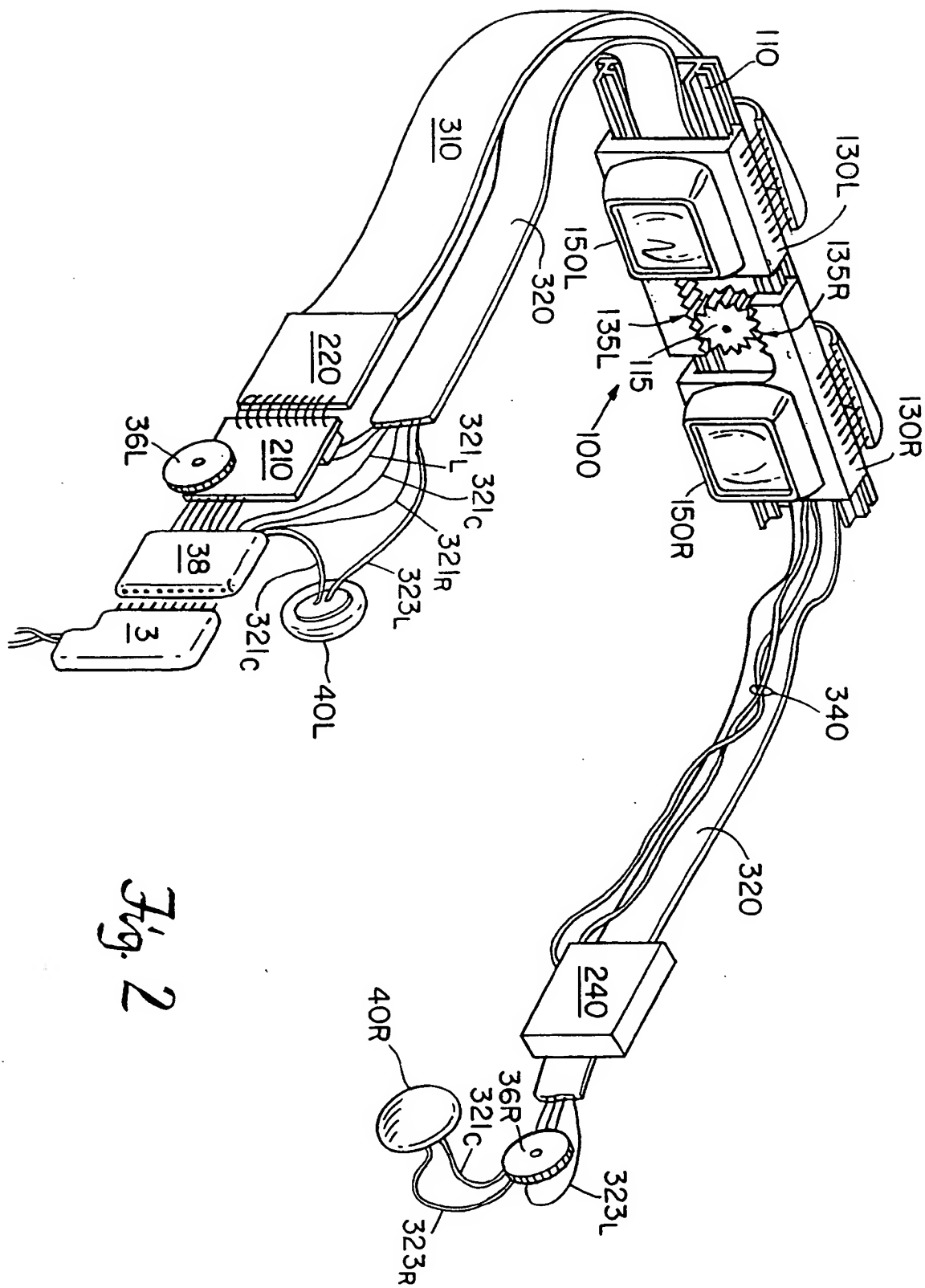
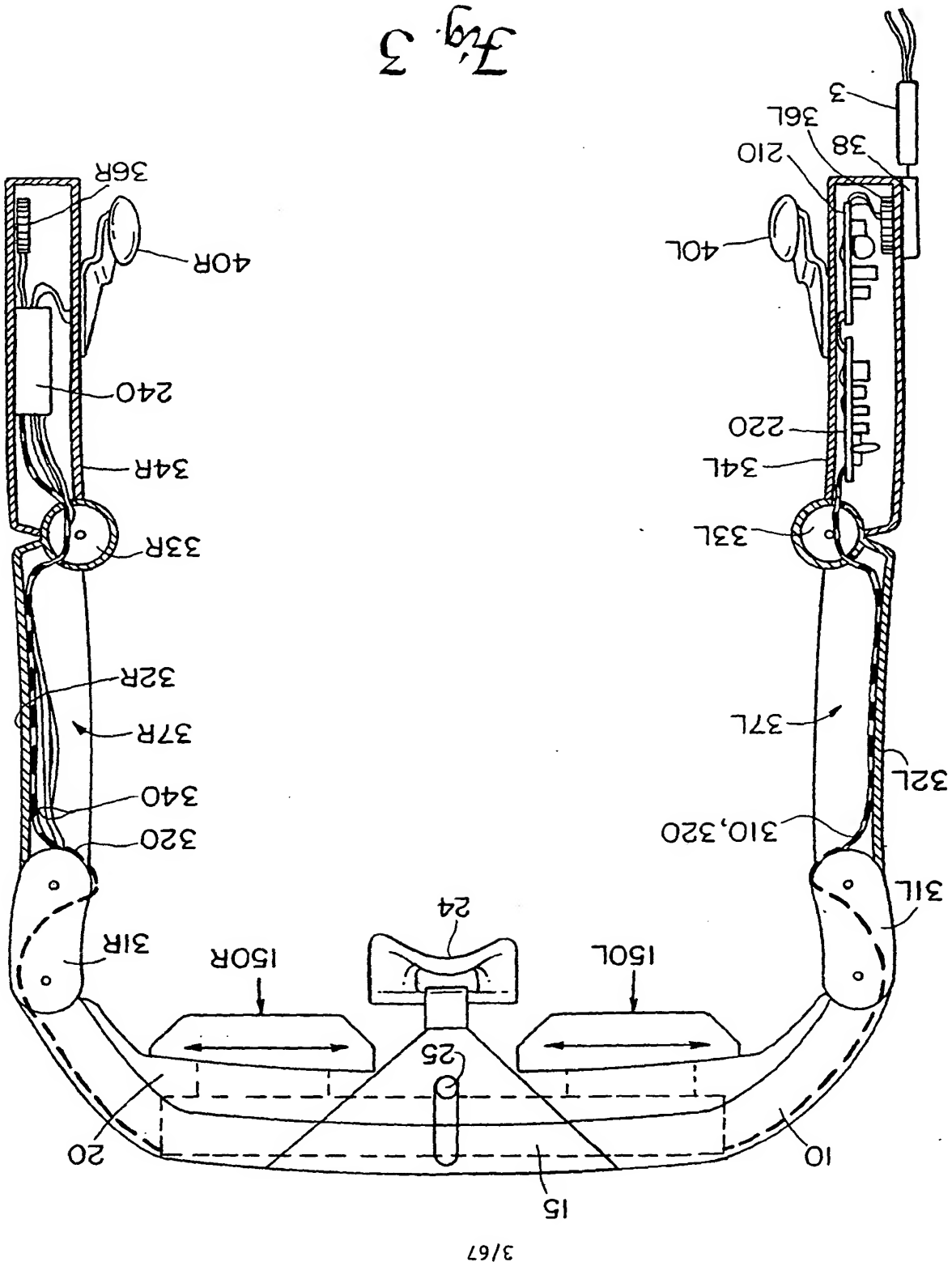
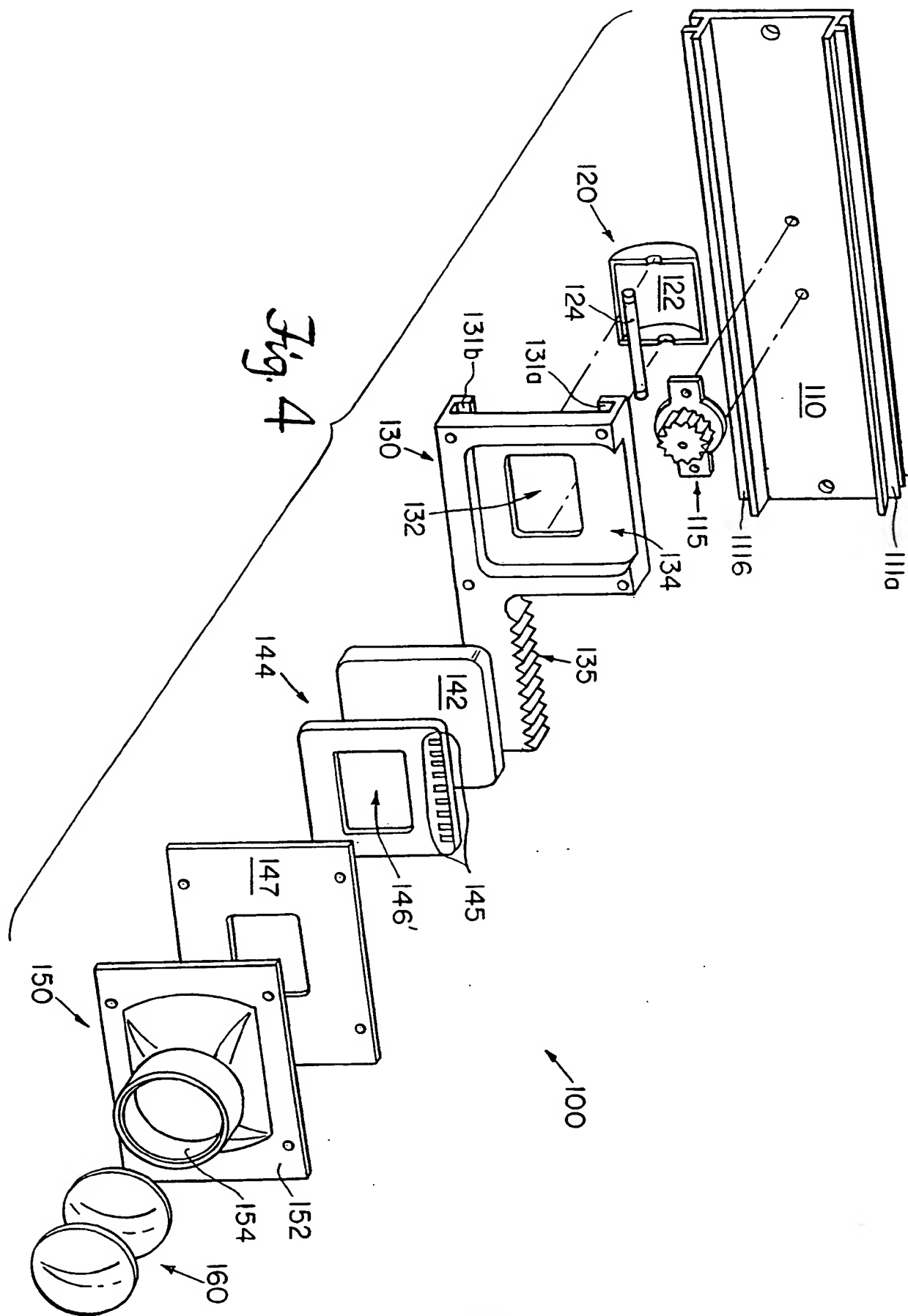
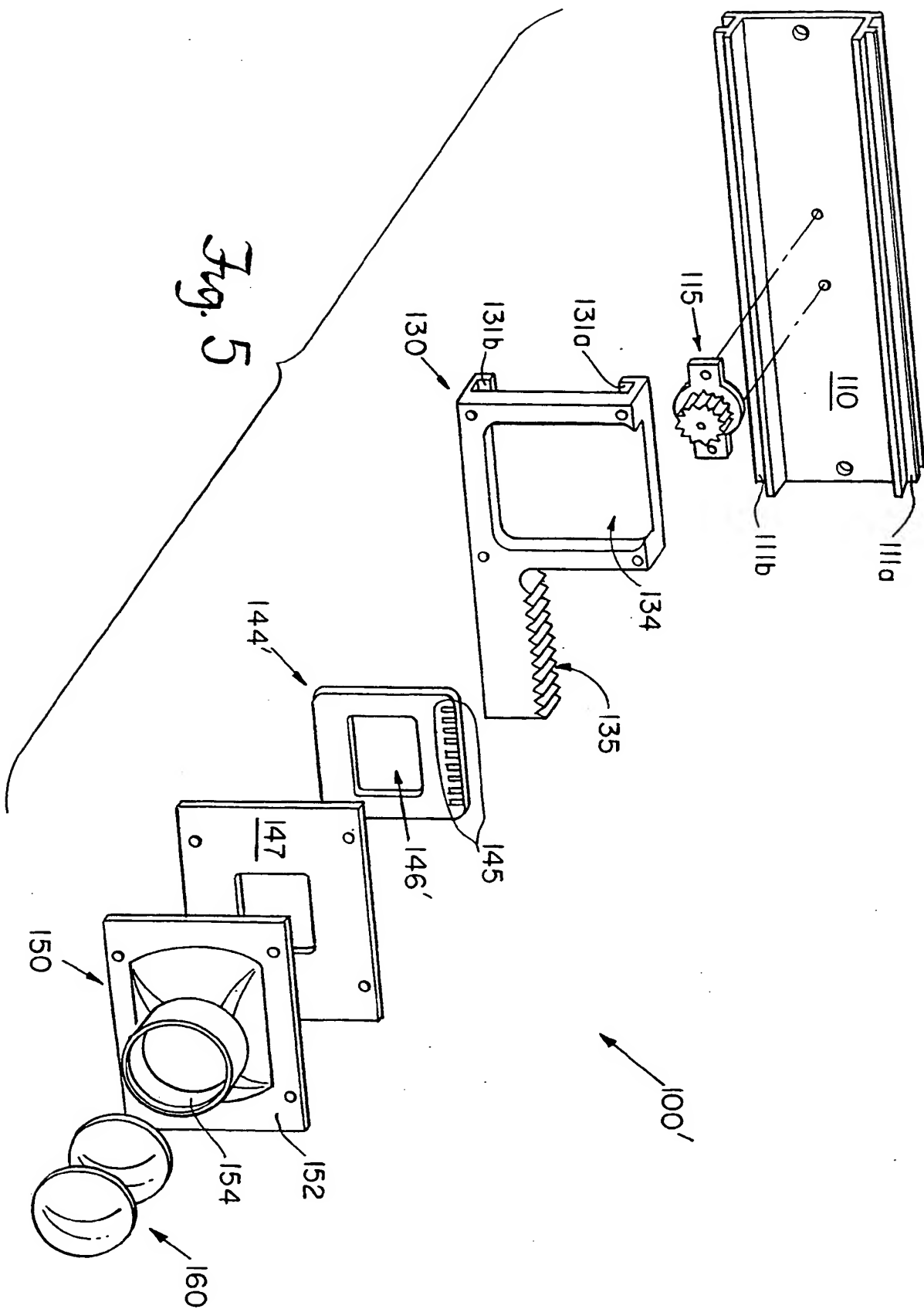


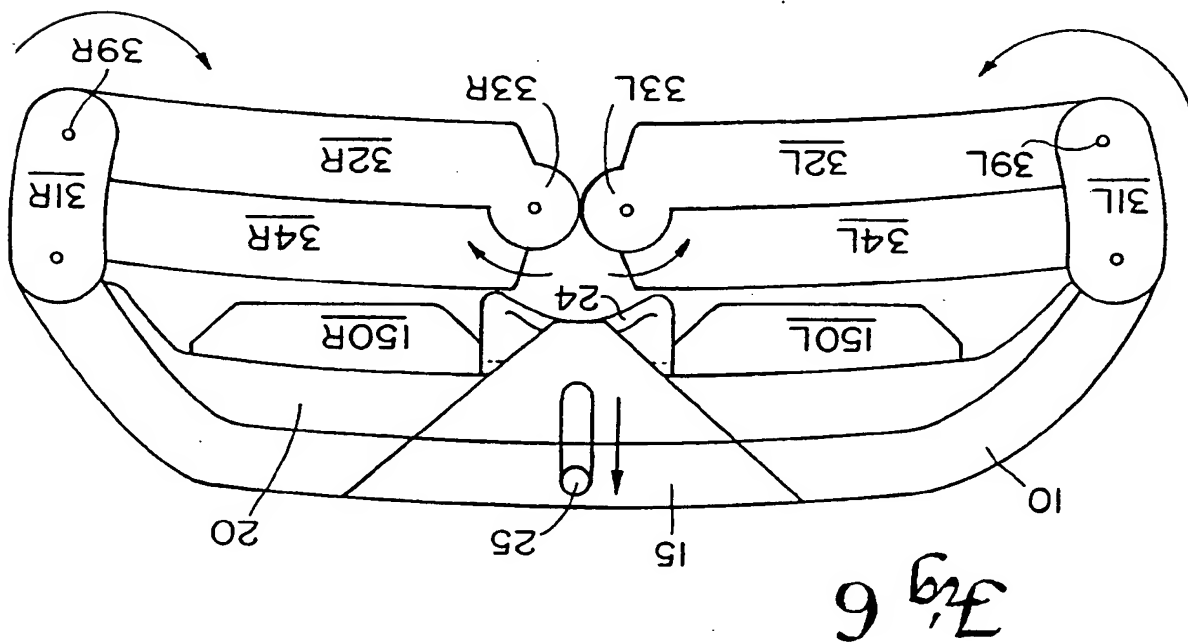
Fig. 2

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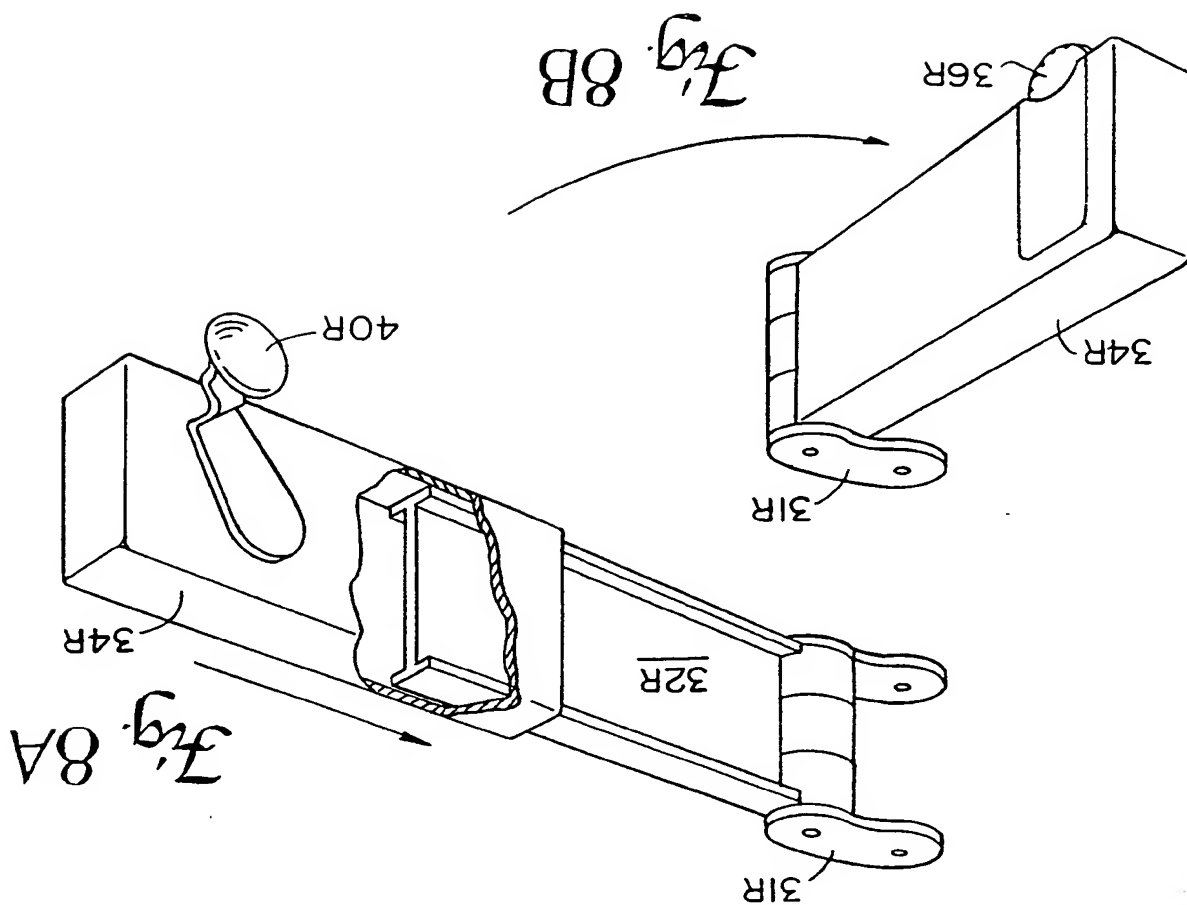


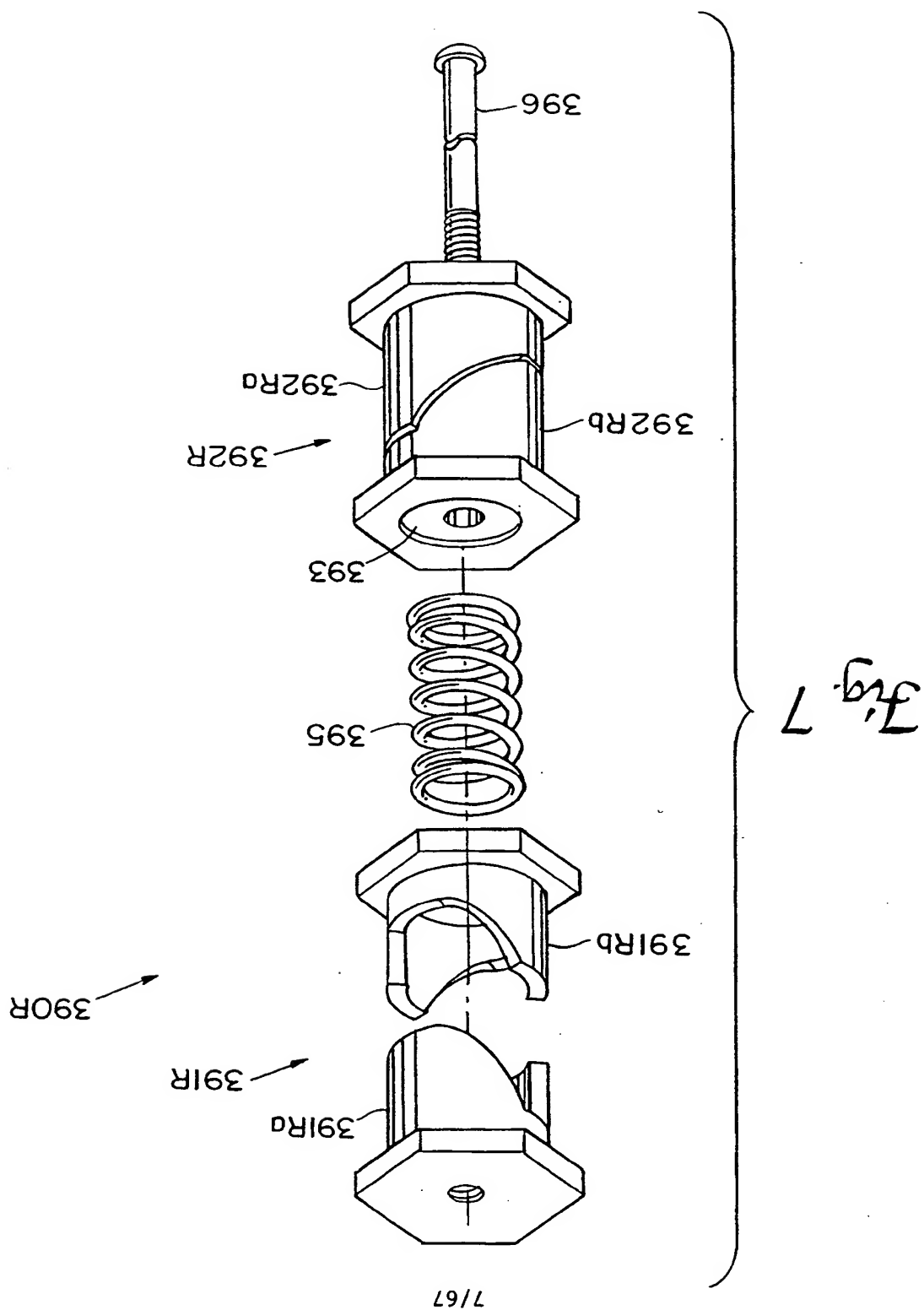






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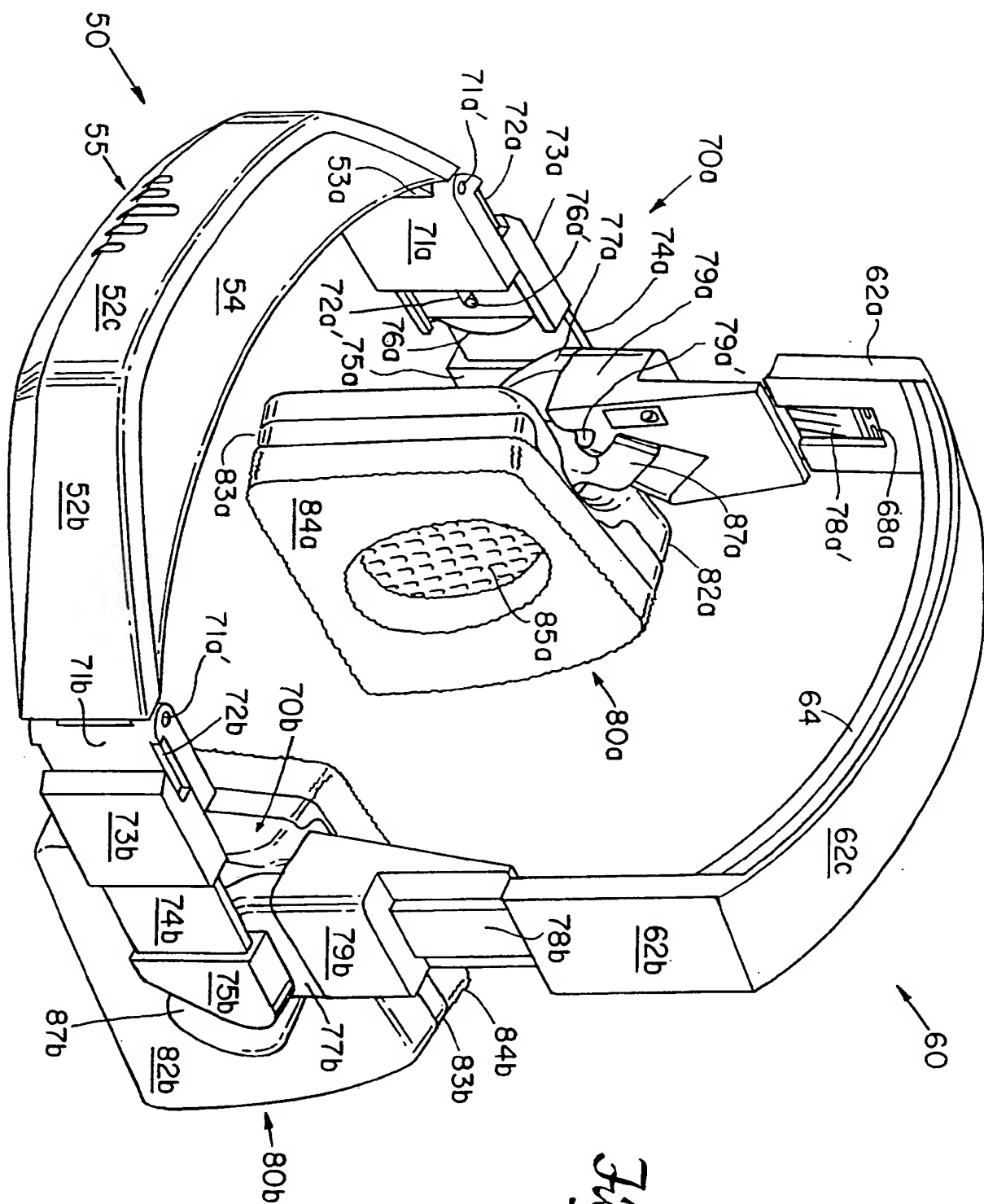


Fig. 9

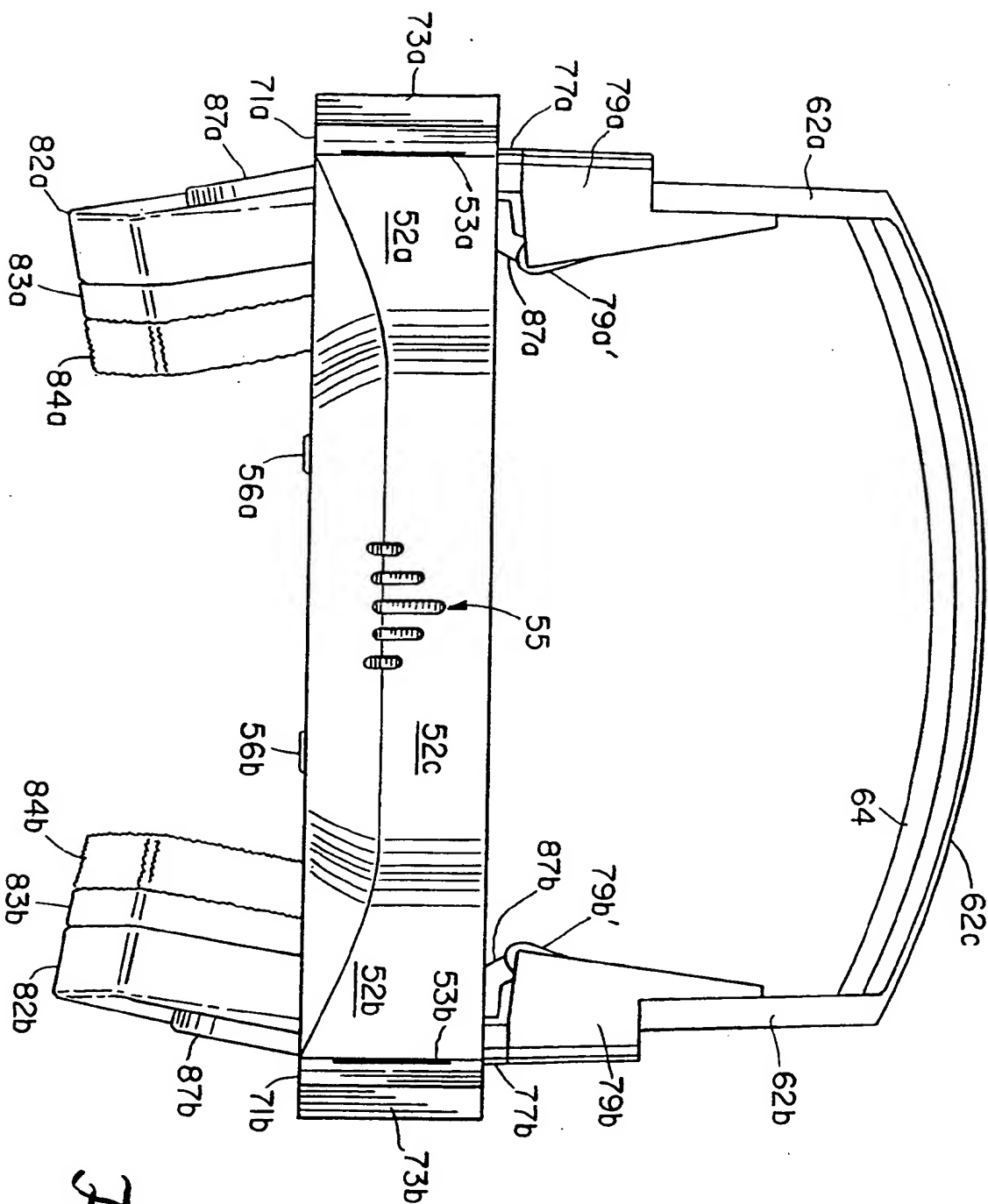


Fig. 10

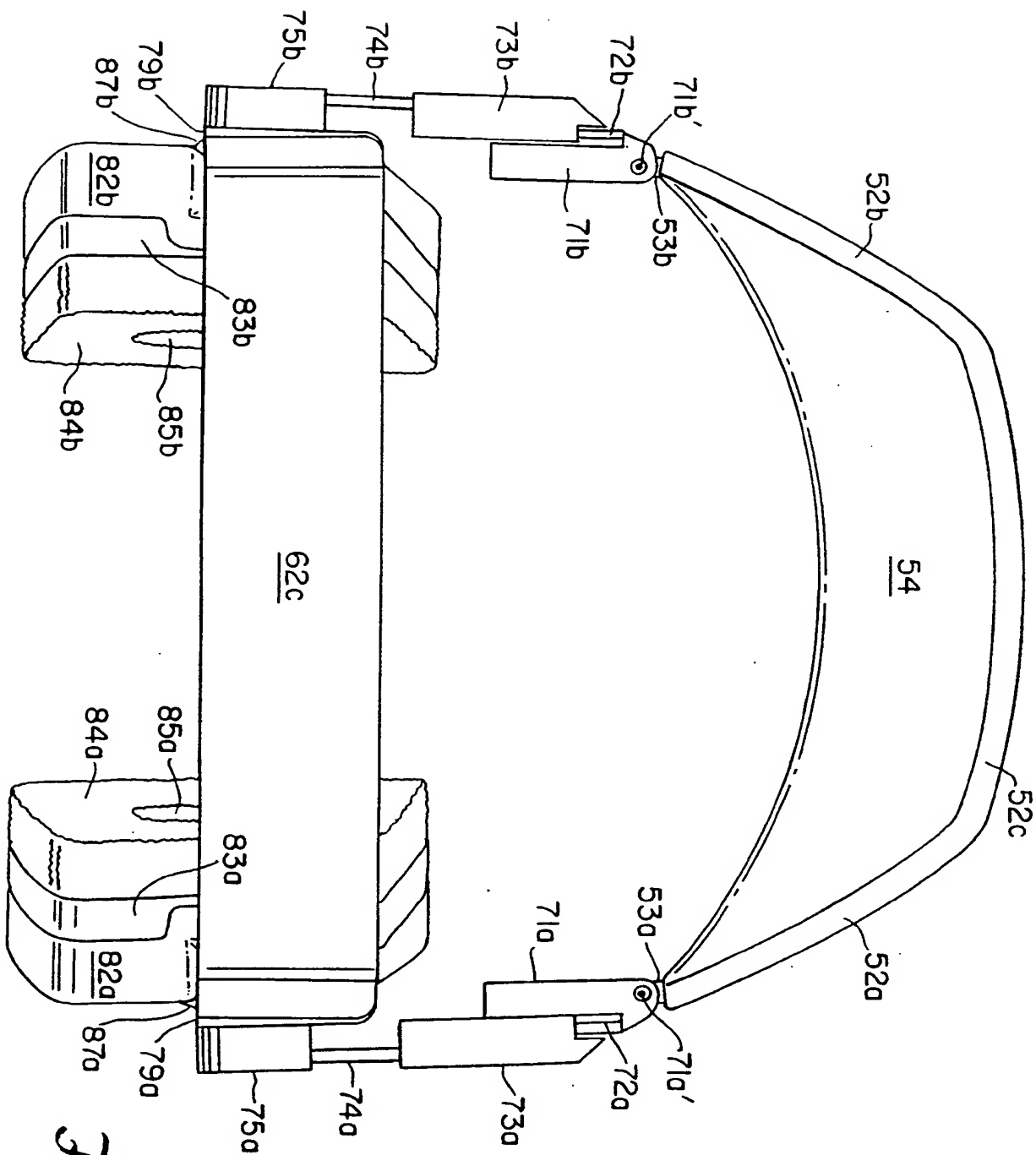
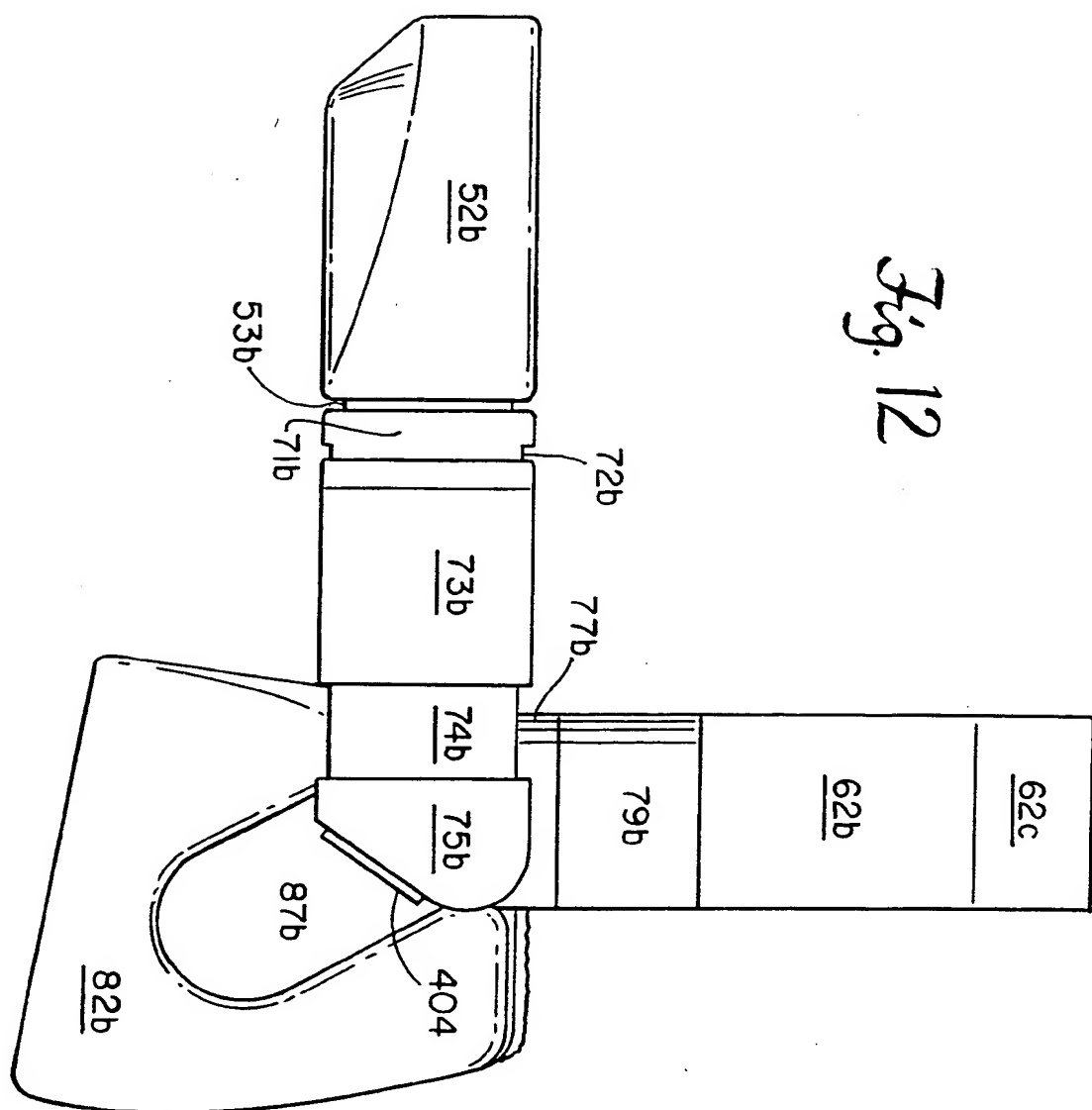


Fig. 11

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Fig. 12



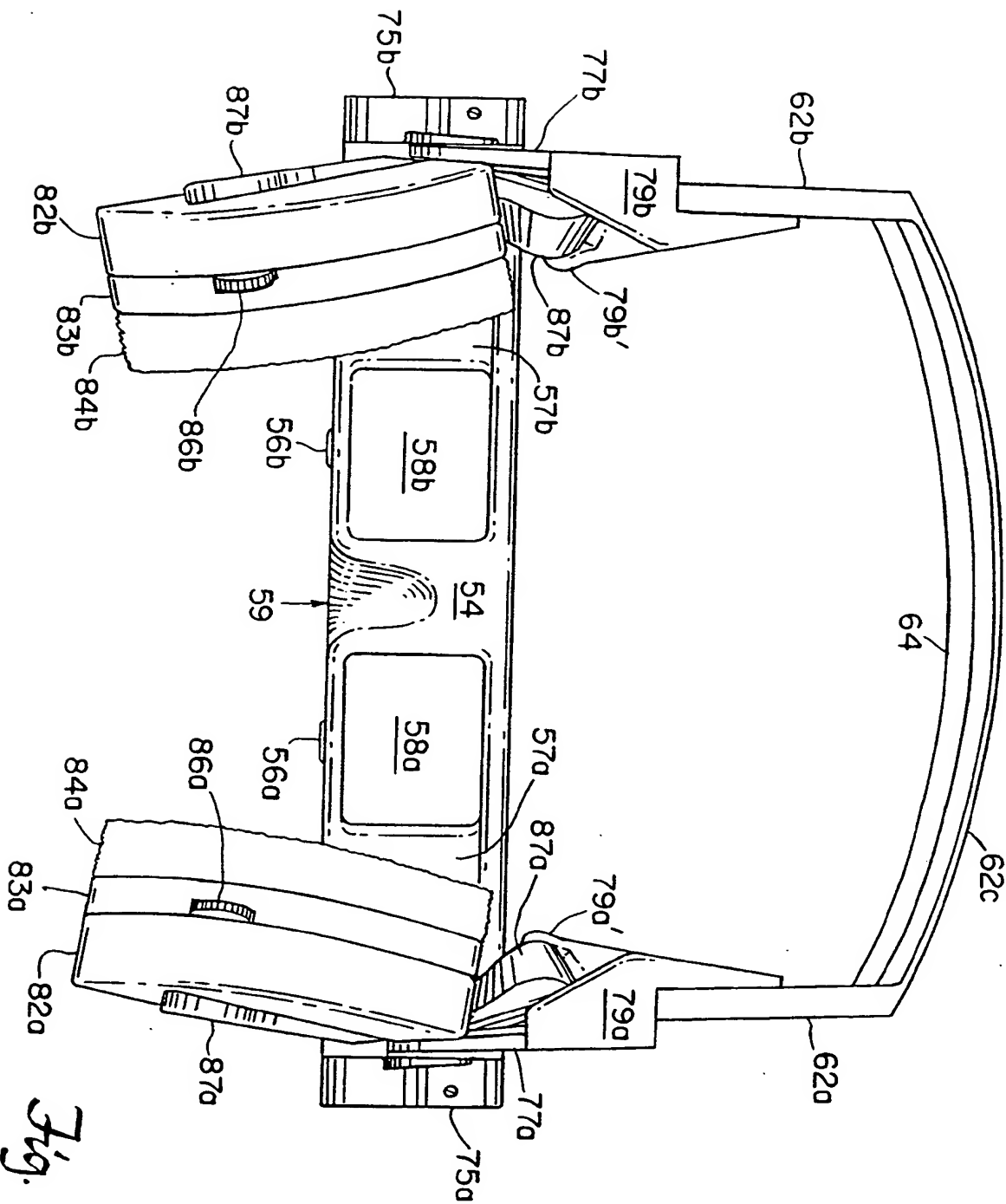
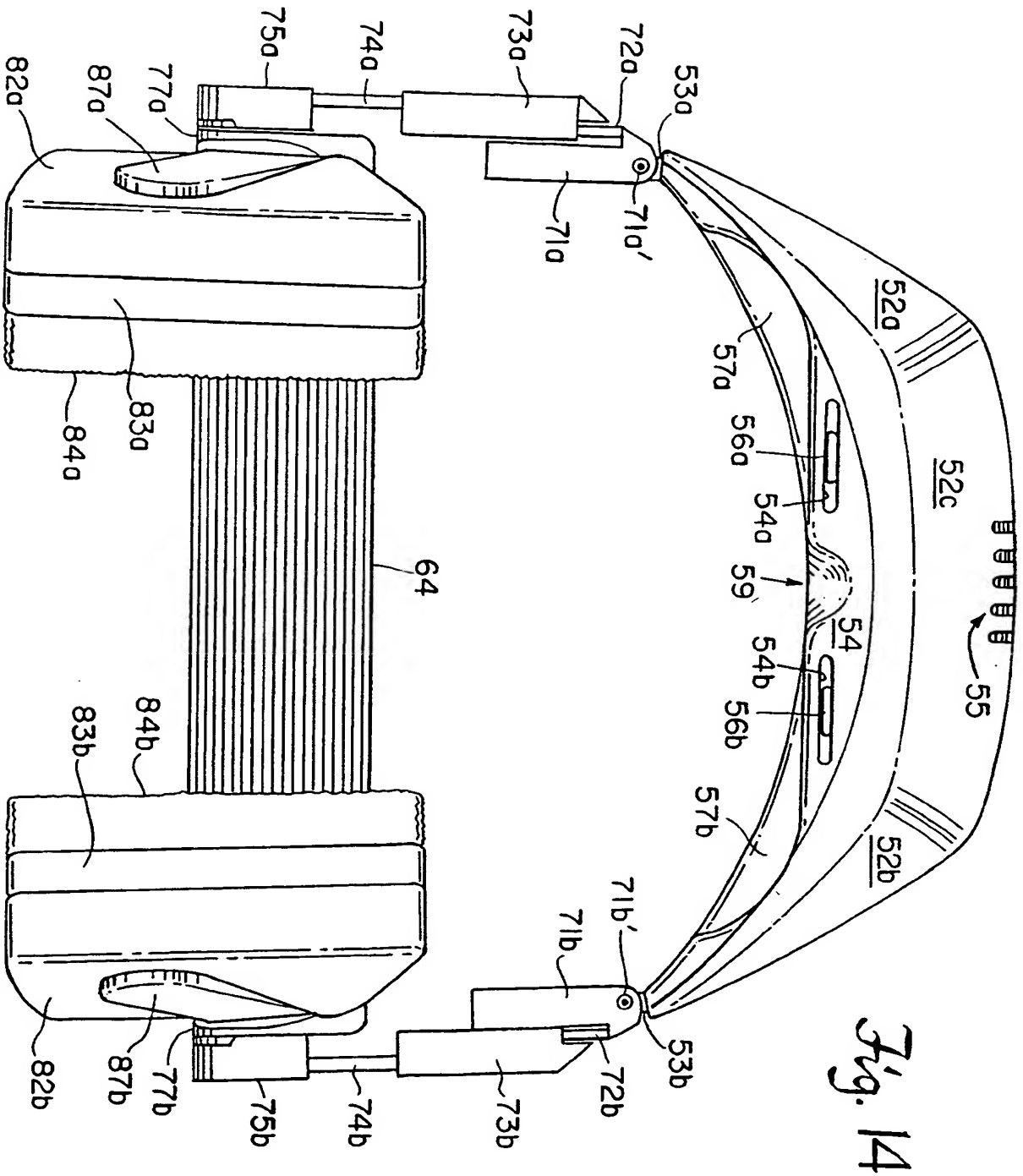


Fig. 13

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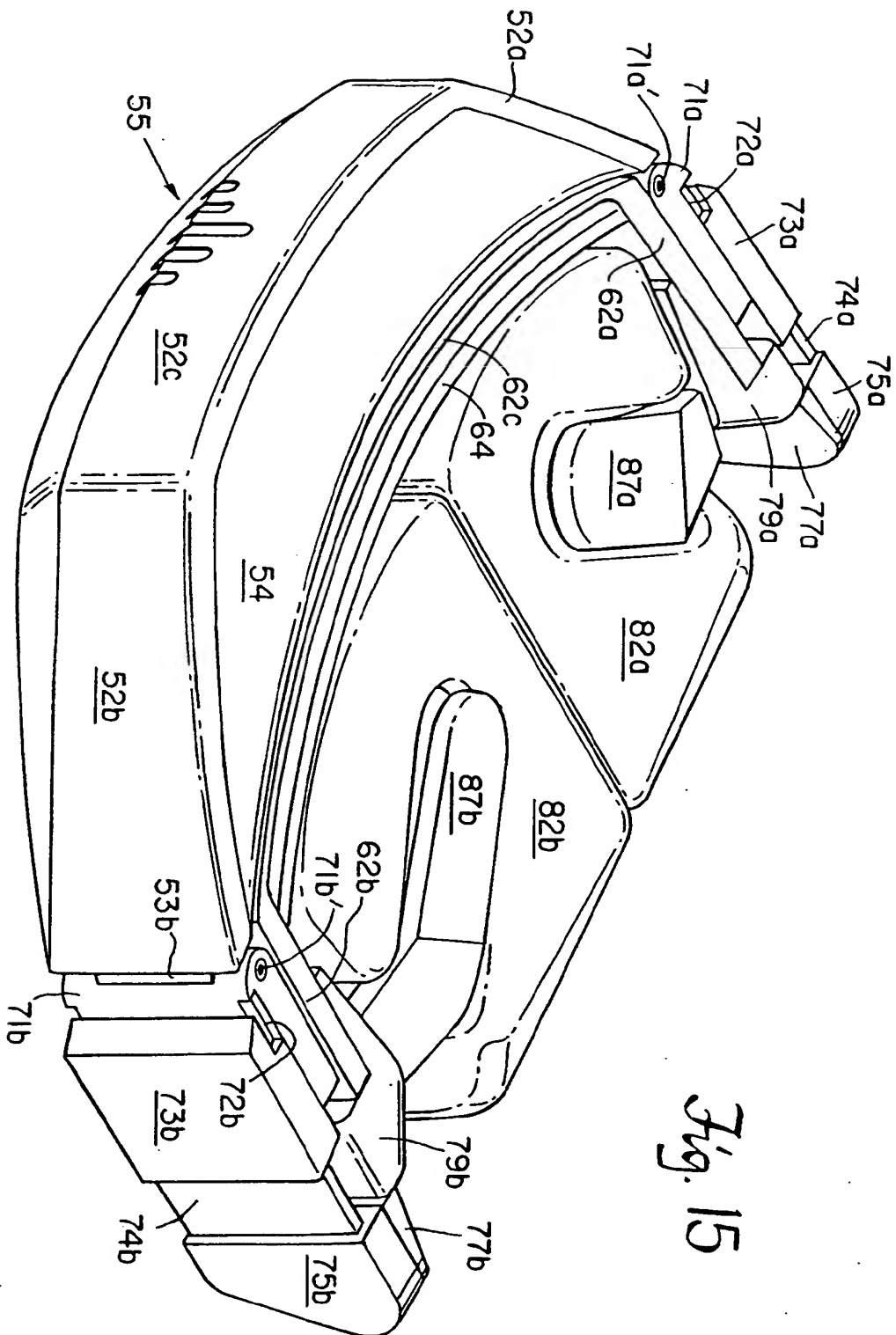
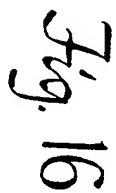


Fig. 15

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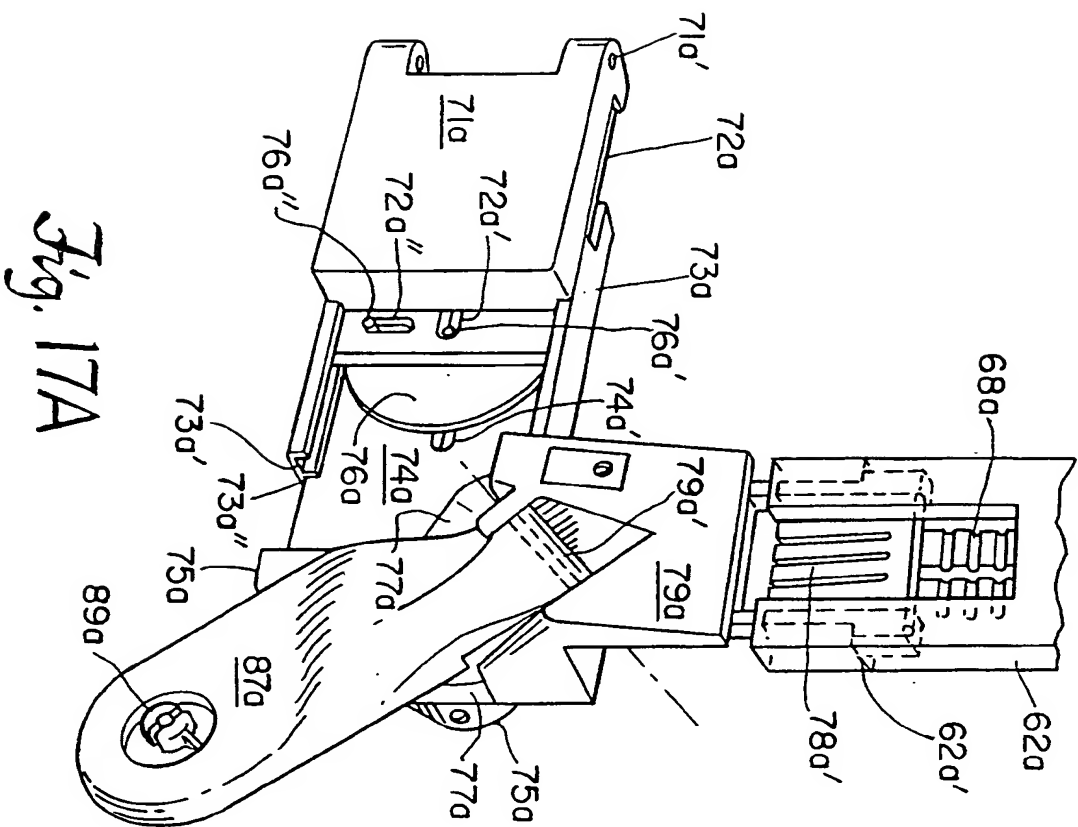


Fig. 17A

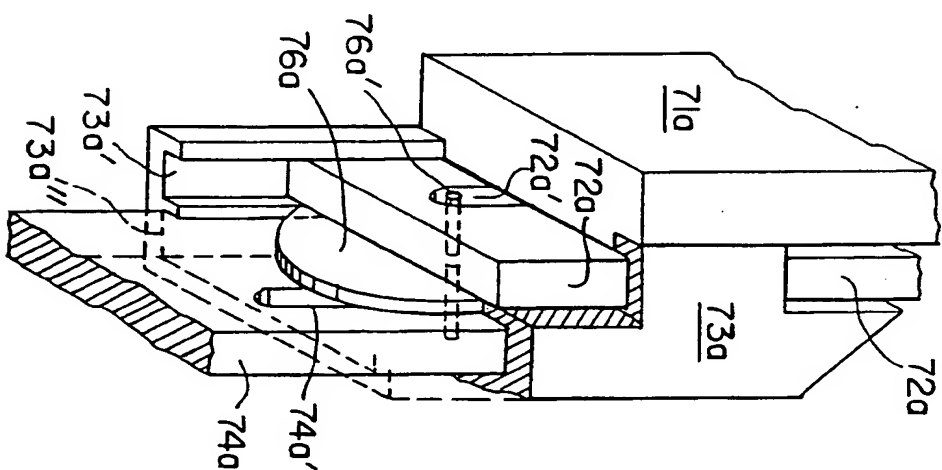


Fig. 17B

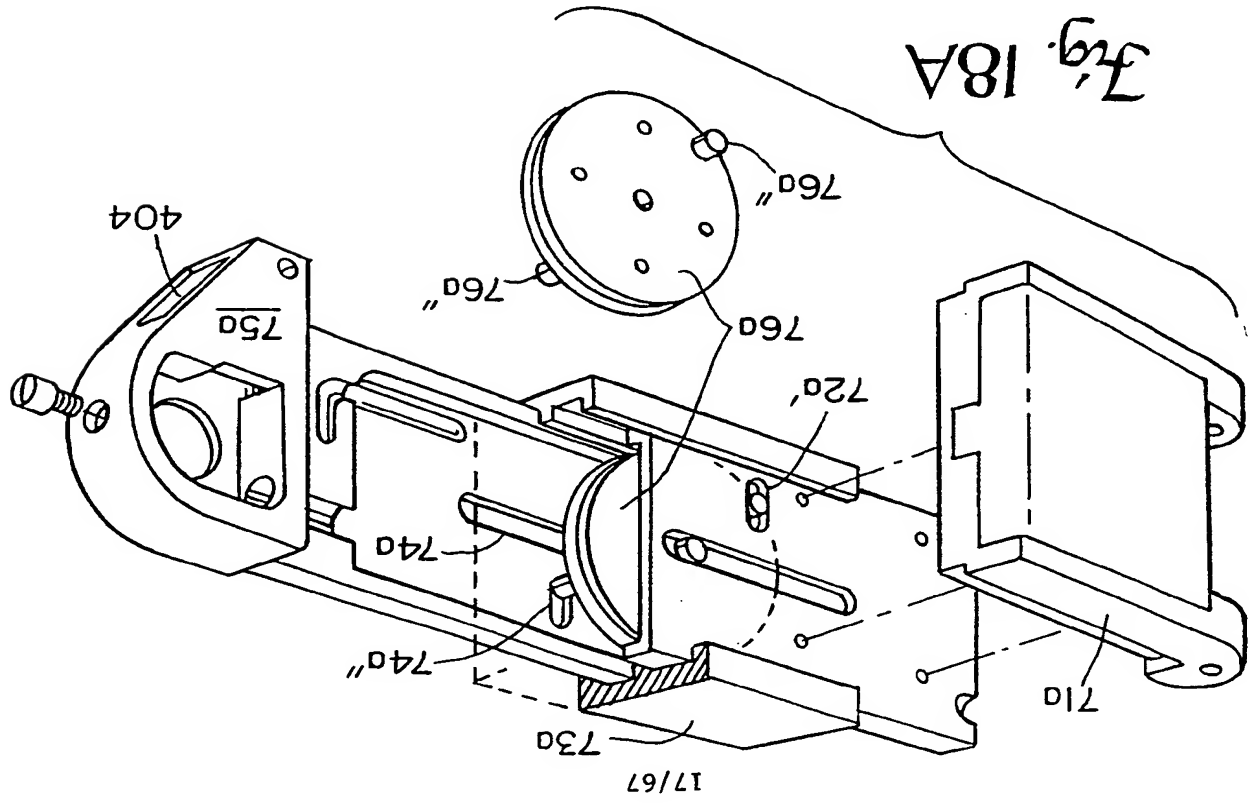
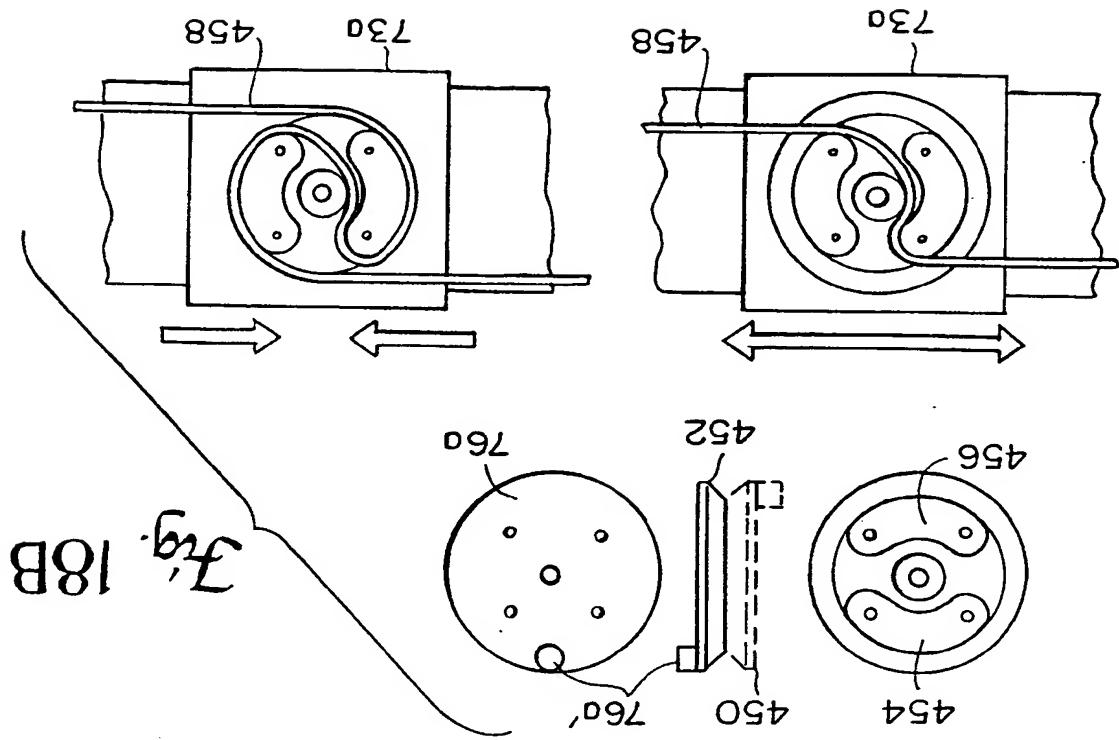


Fig. 21

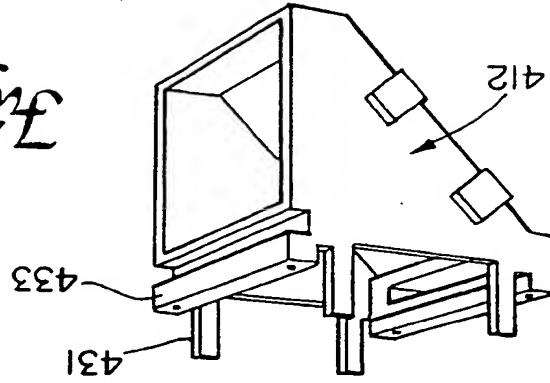
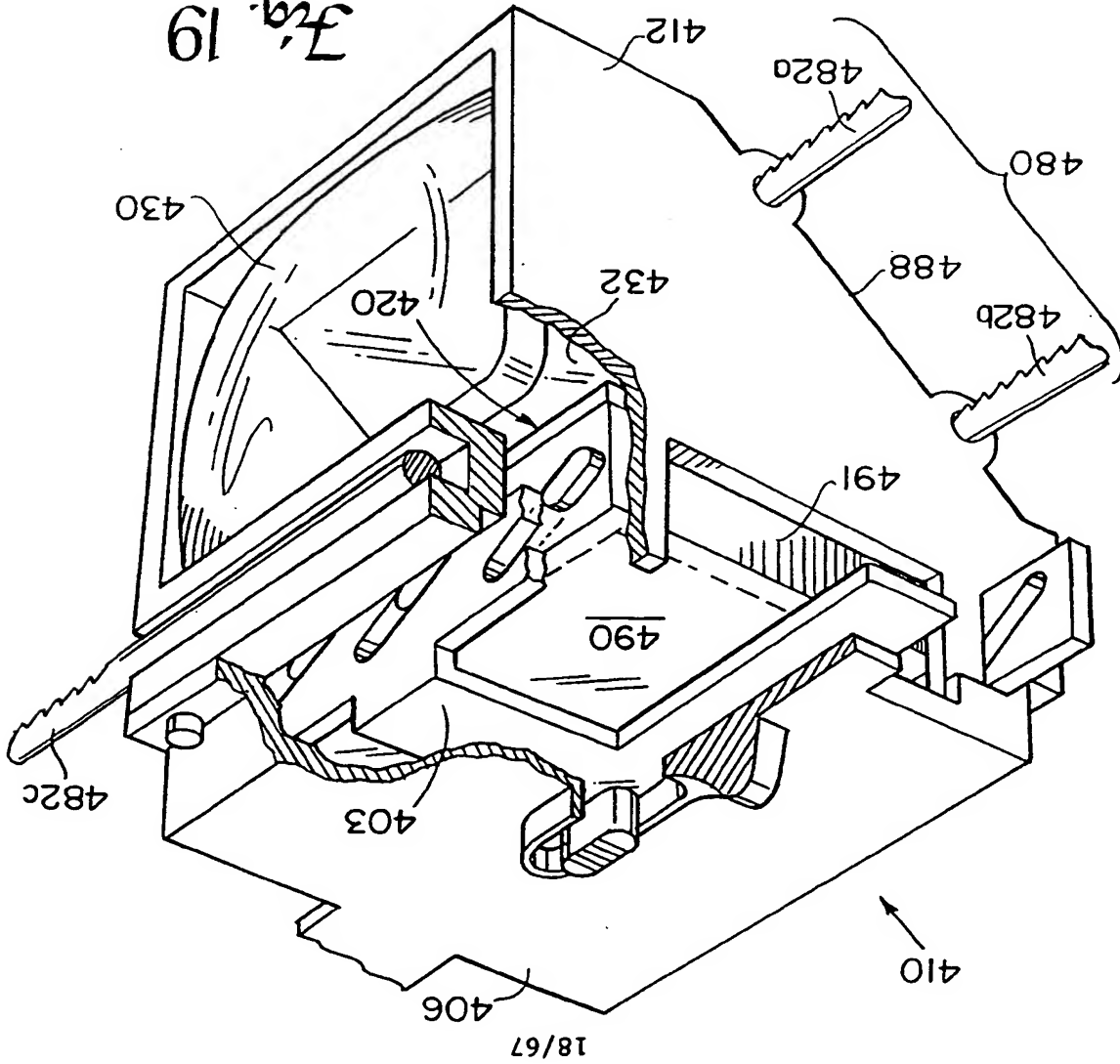
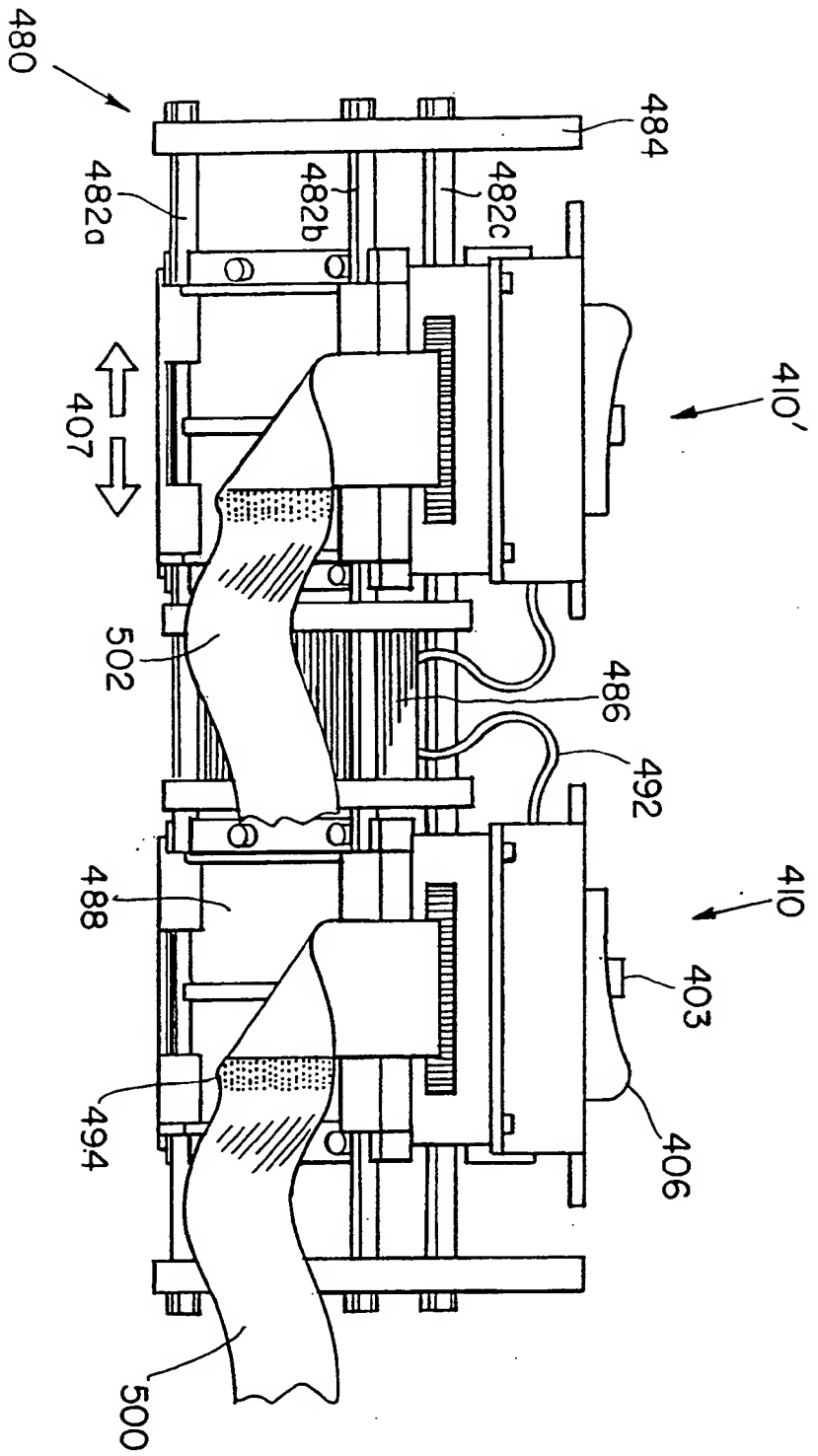
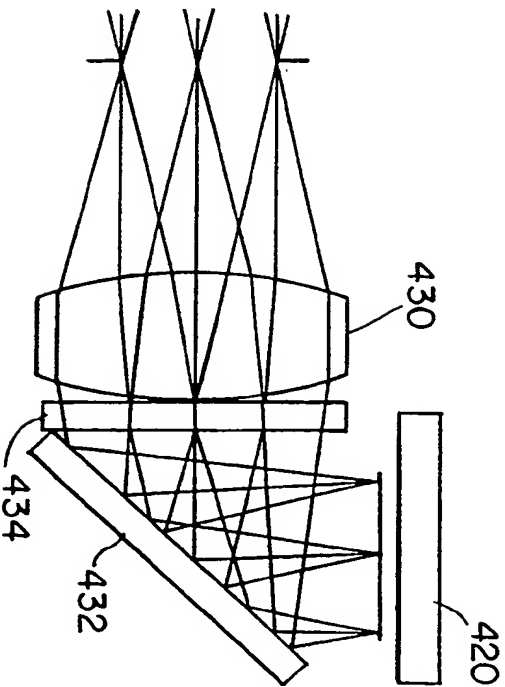
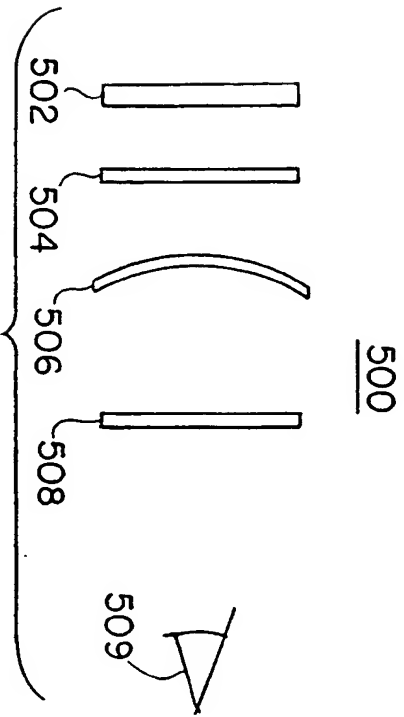
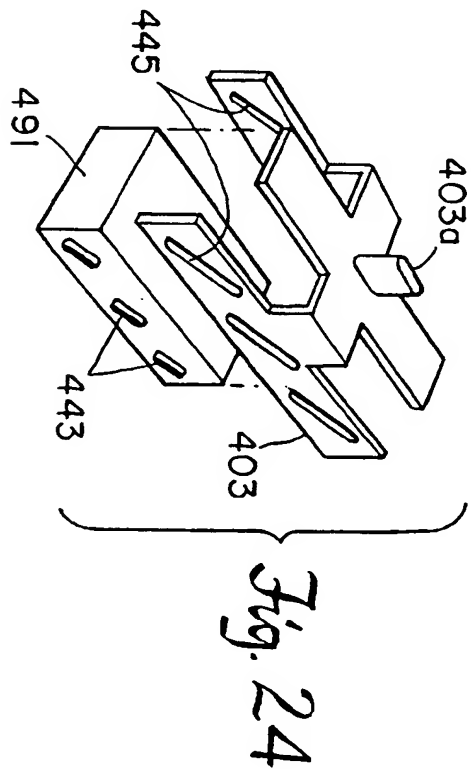
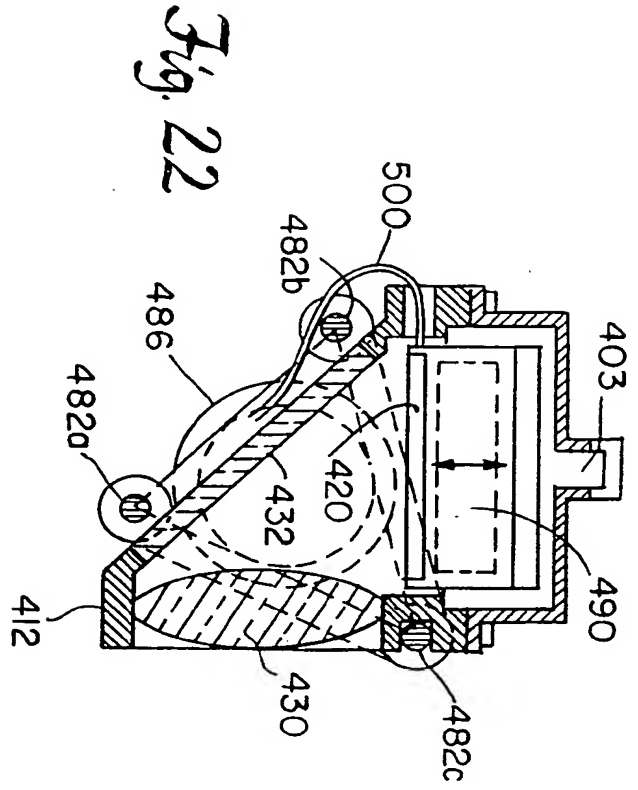


Fig. 19







440

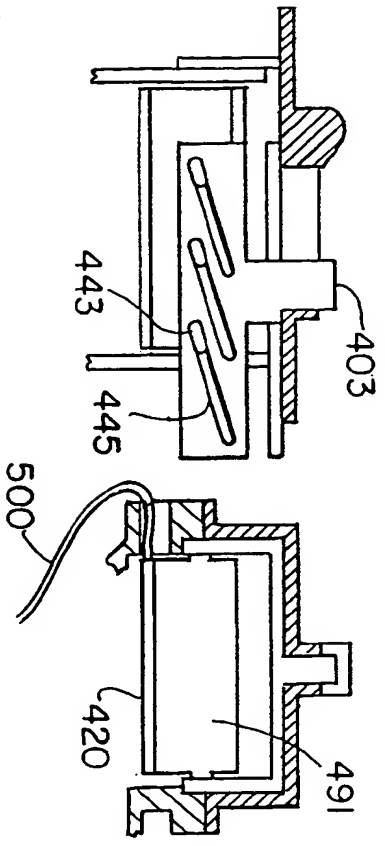


Fig. 23A

442

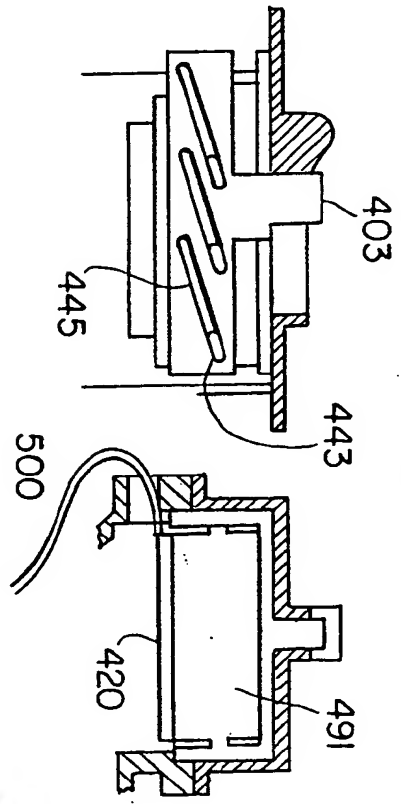


Fig. 23B

Fig. 27

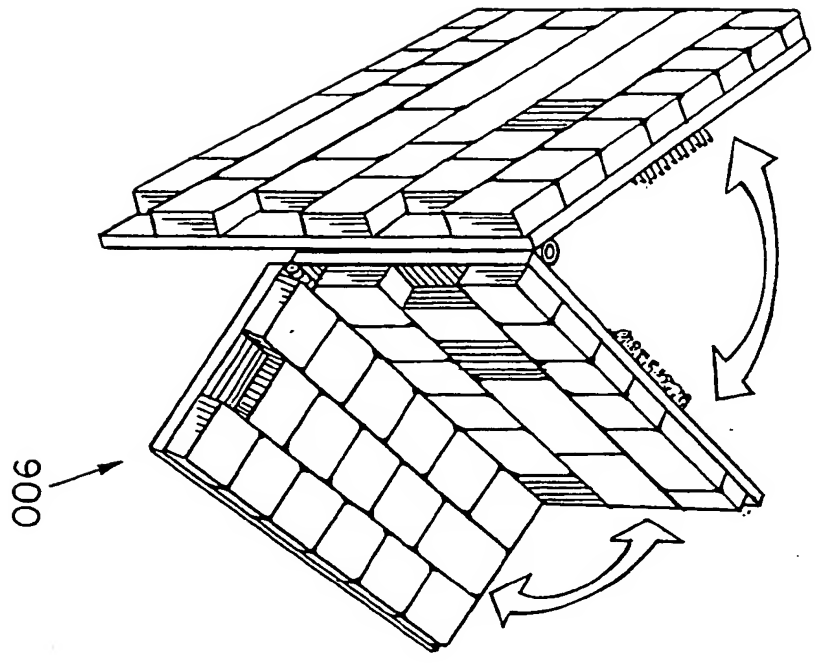
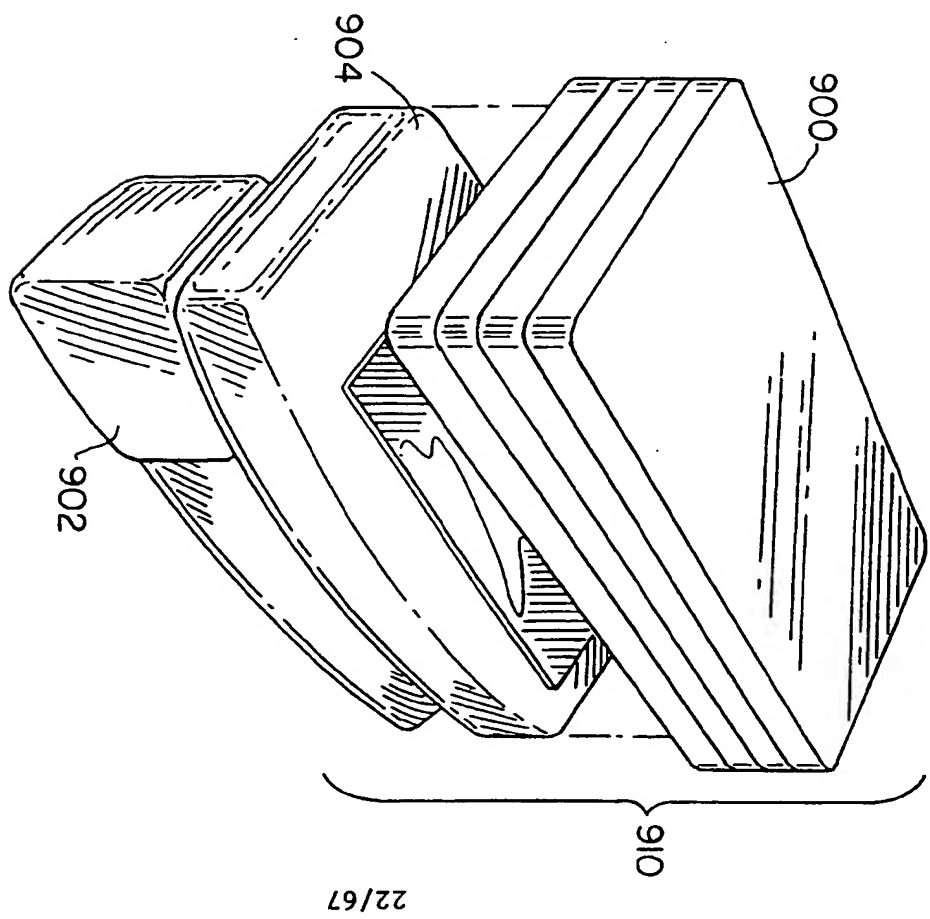
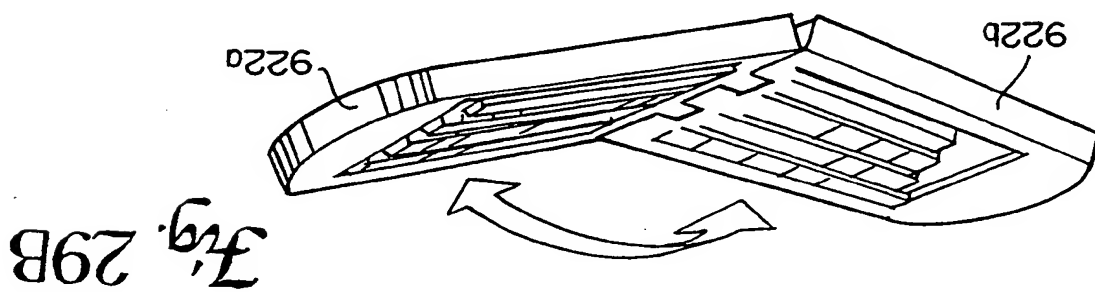
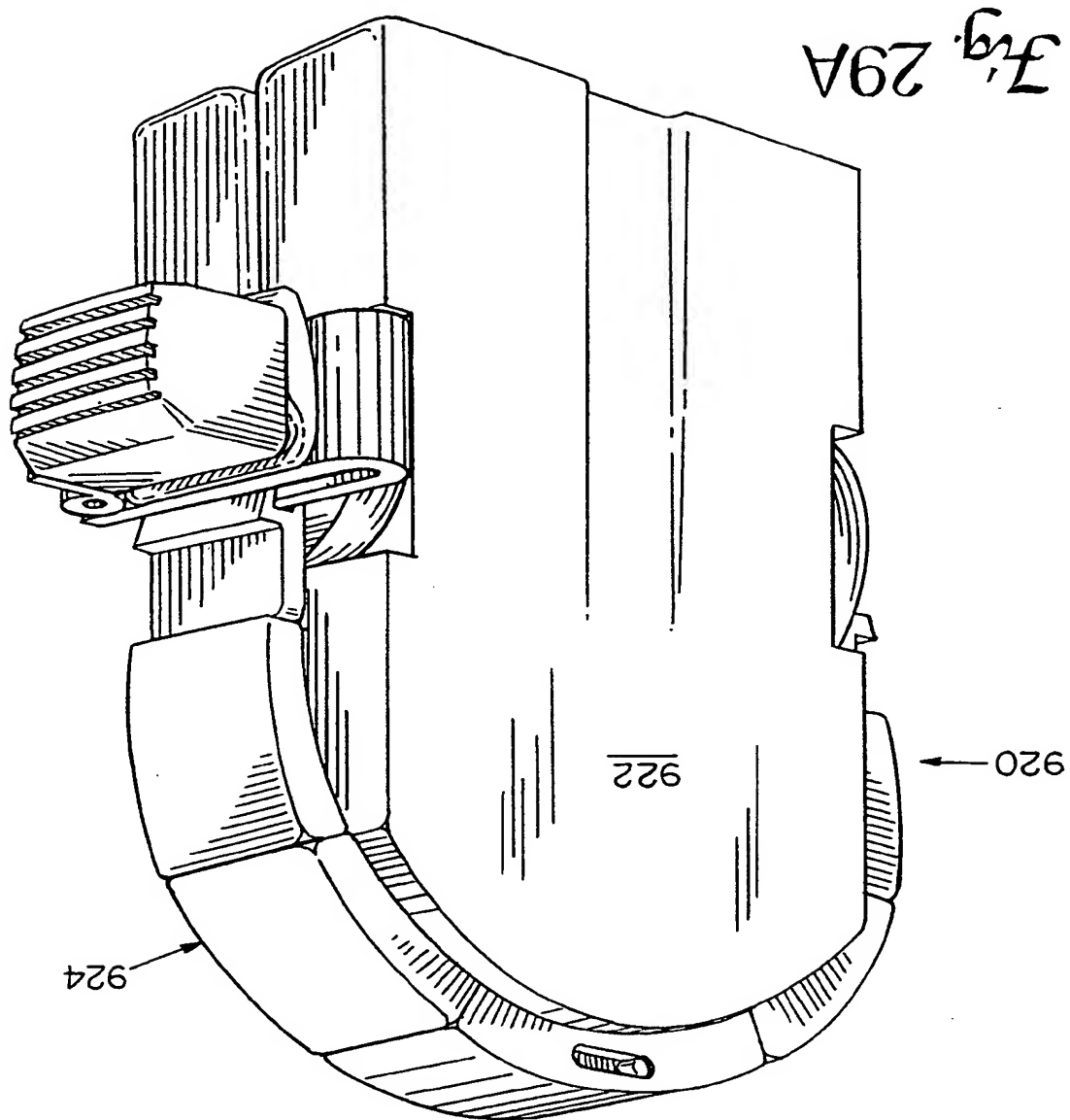


Fig. 28





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Fig. 30A

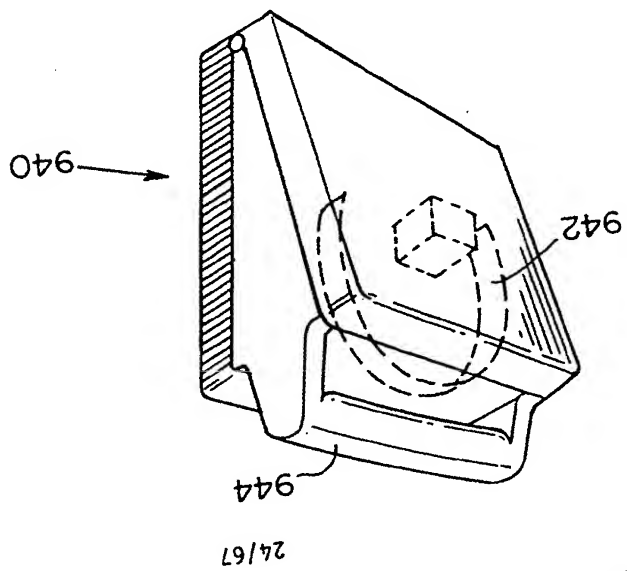


Fig. 30B

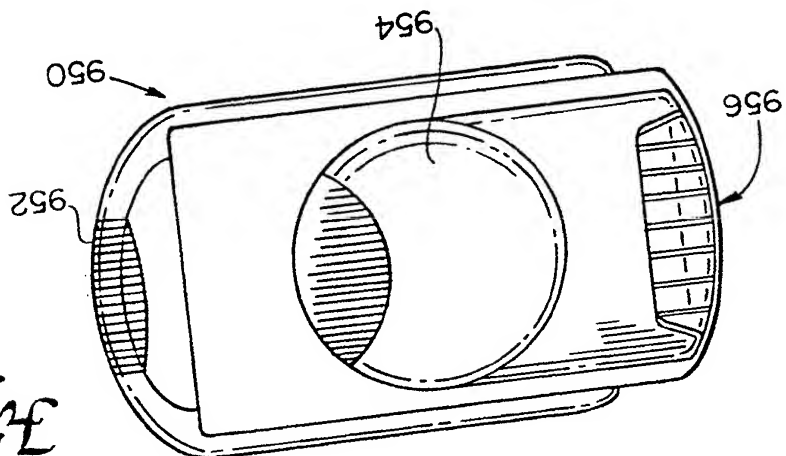
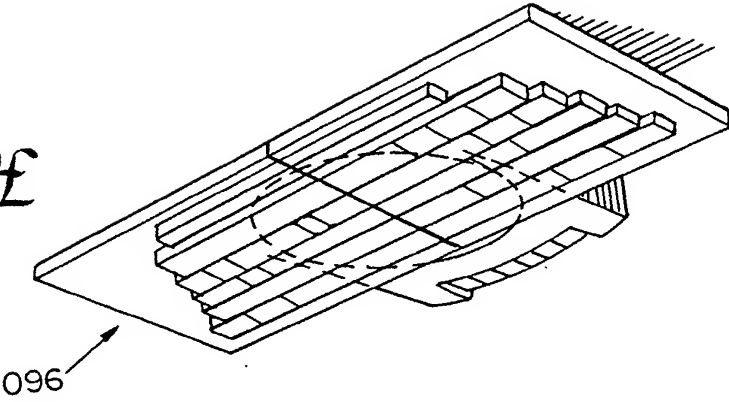
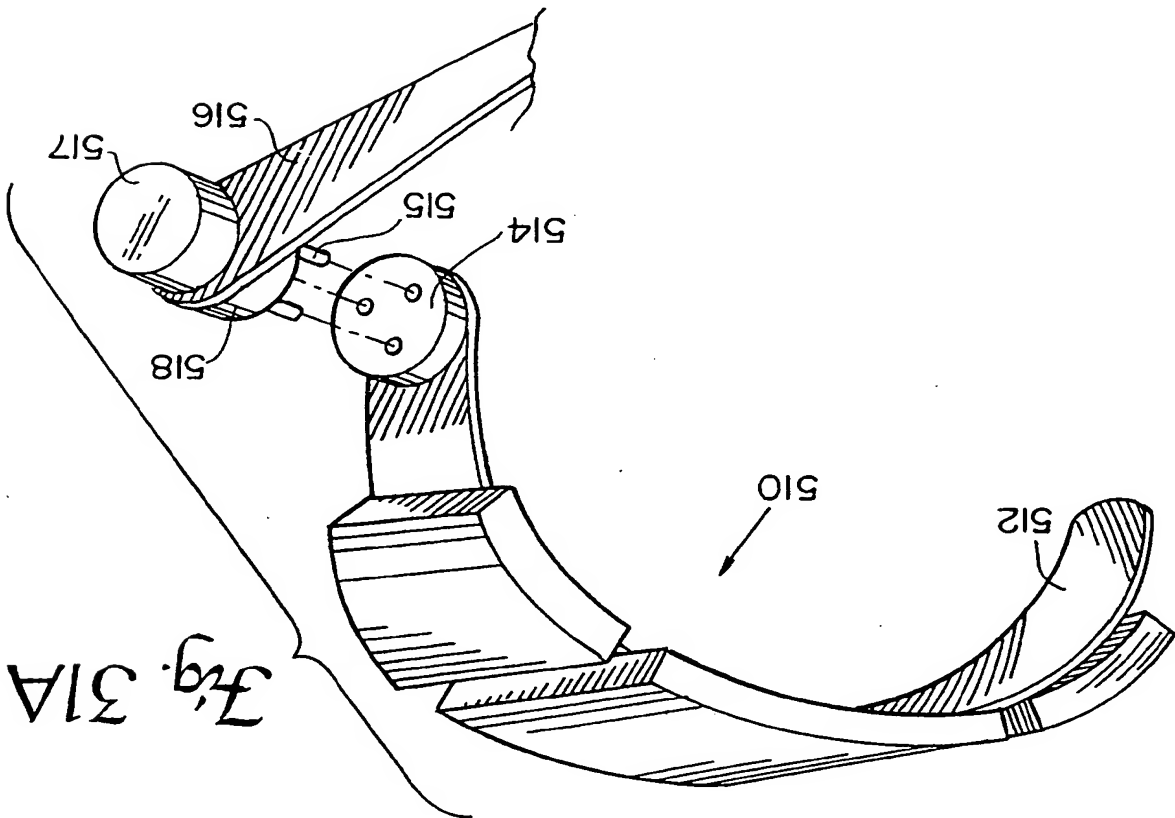
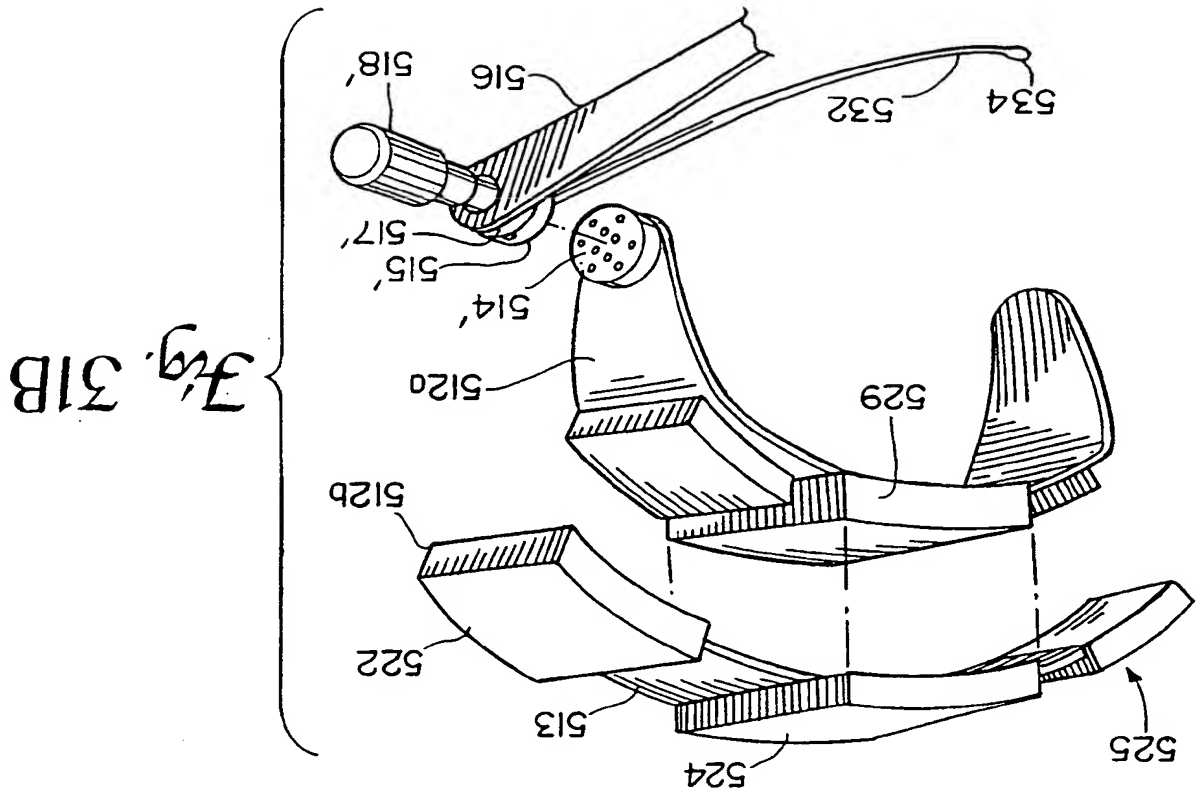


Fig. 30C





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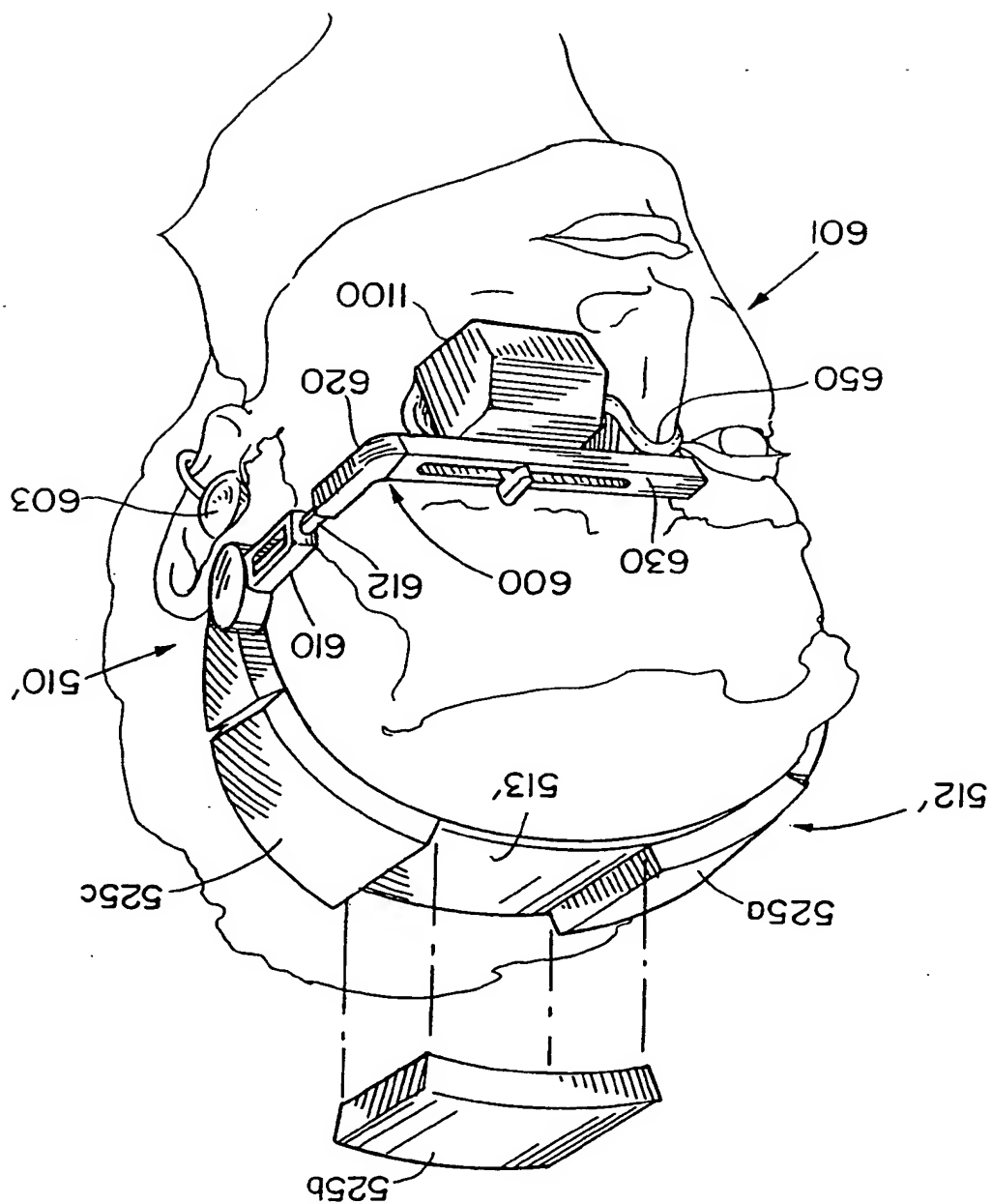


Fig. 32A

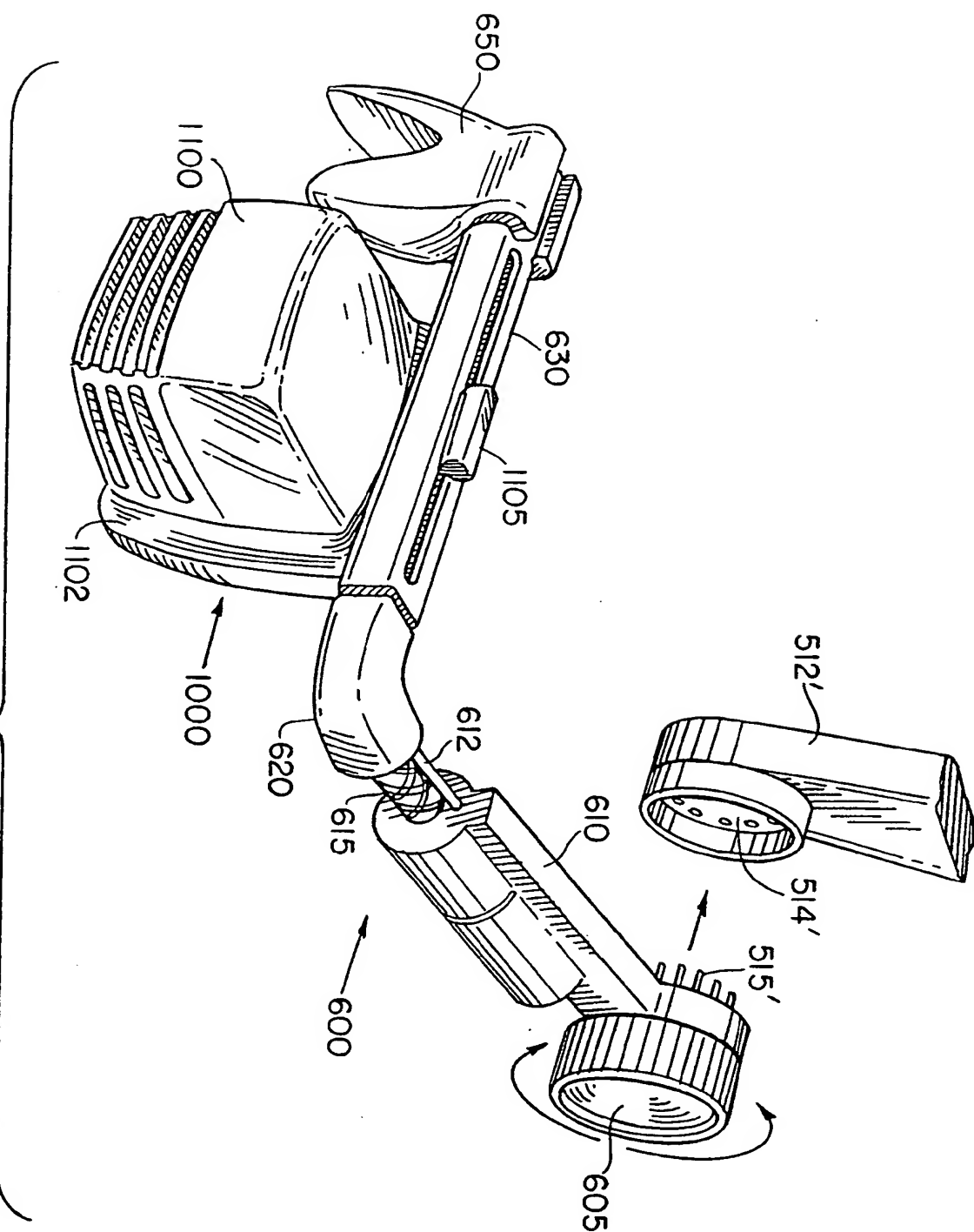
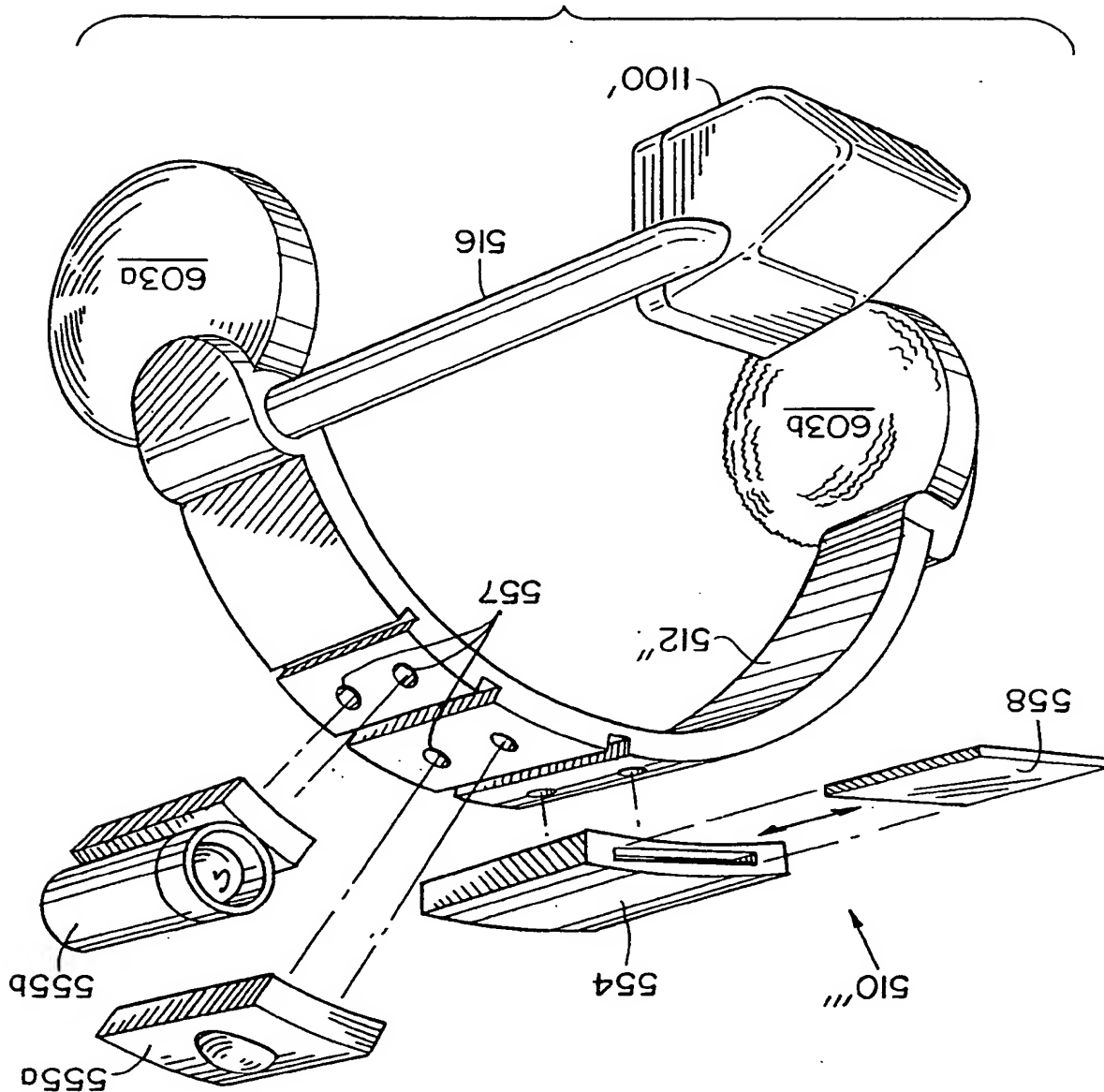


Fig. 32B

Fig. 33



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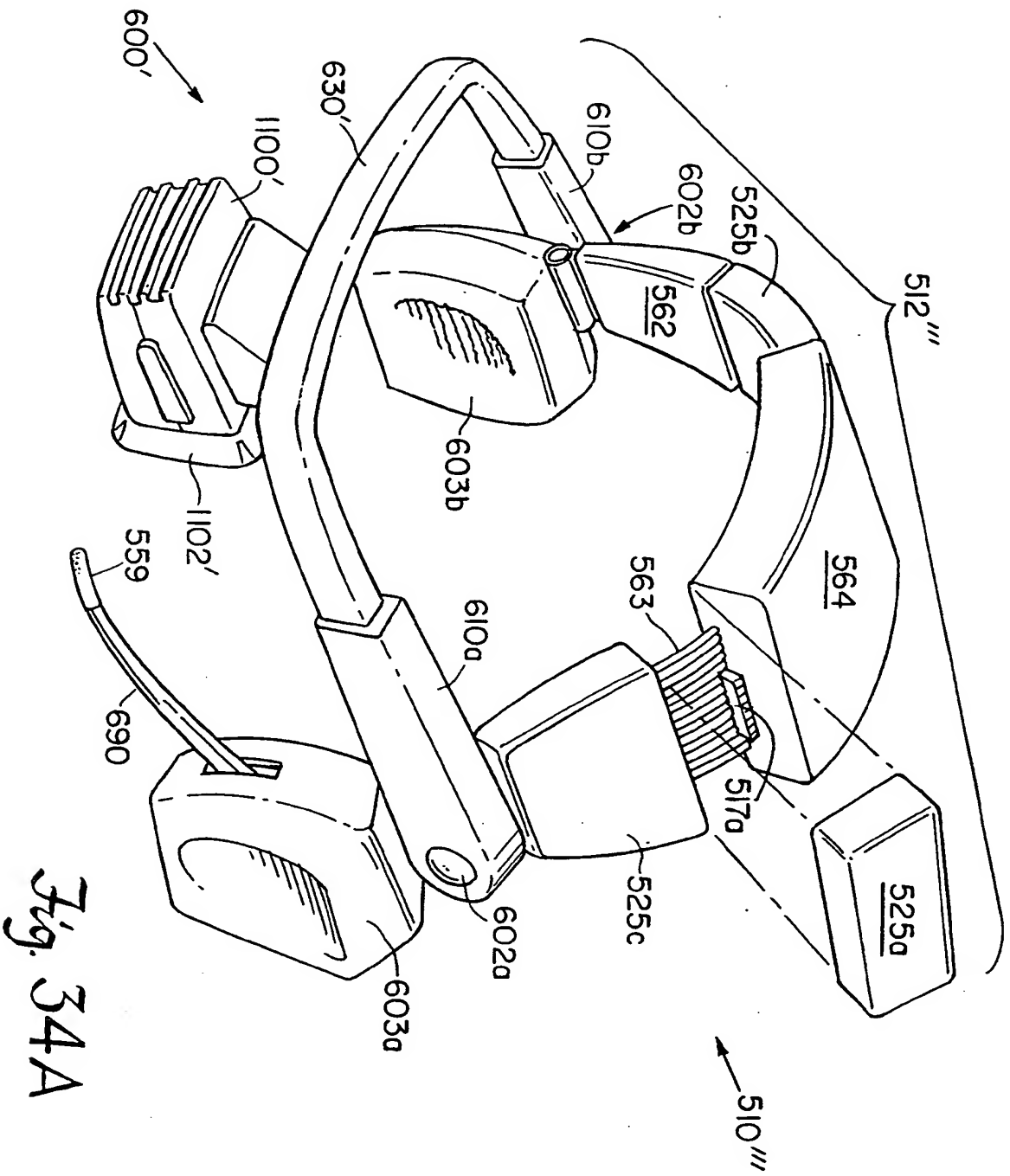


Fig. 34A

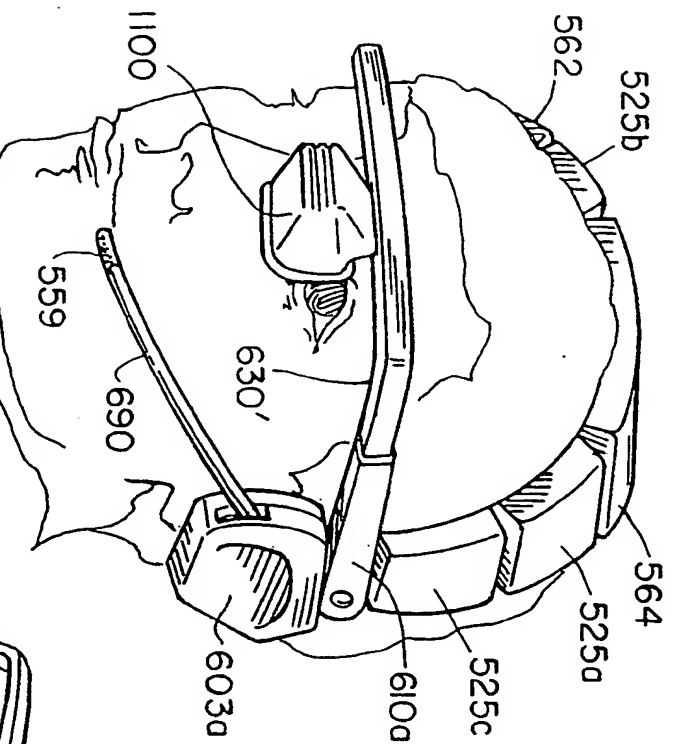


Fig. 34D

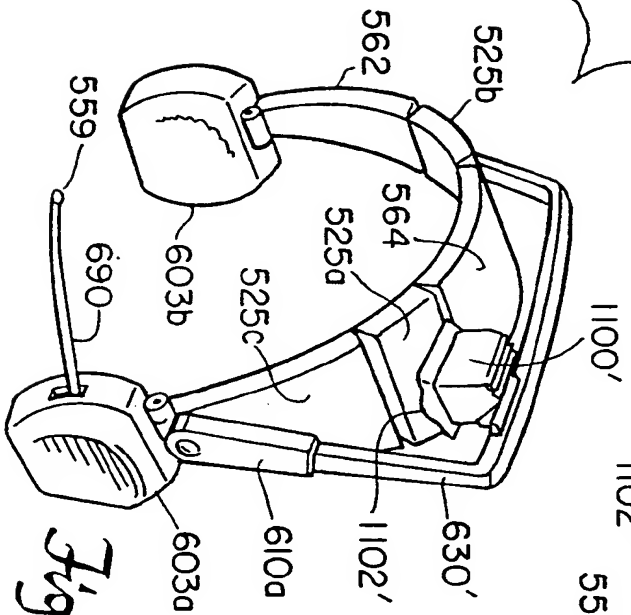


Fig. 34C

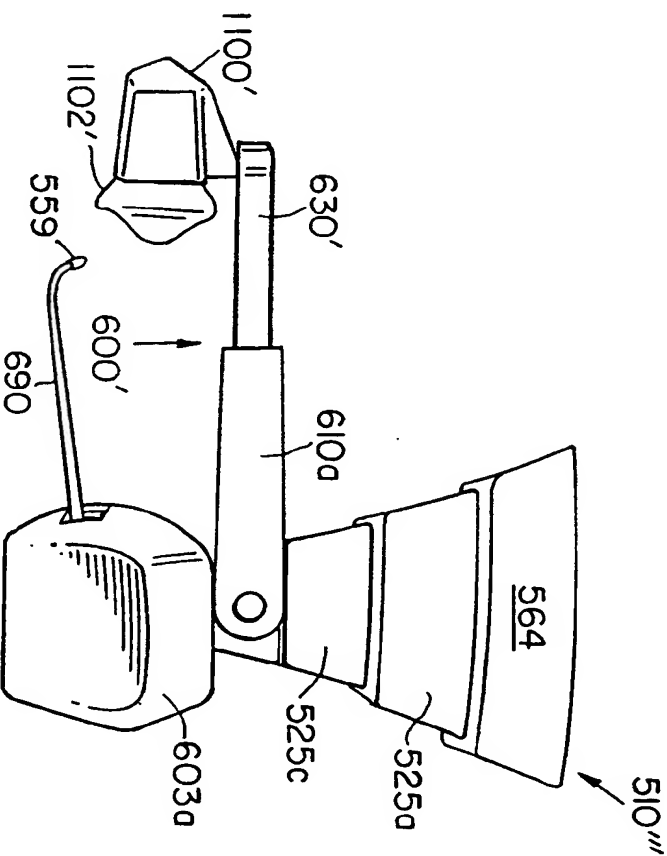
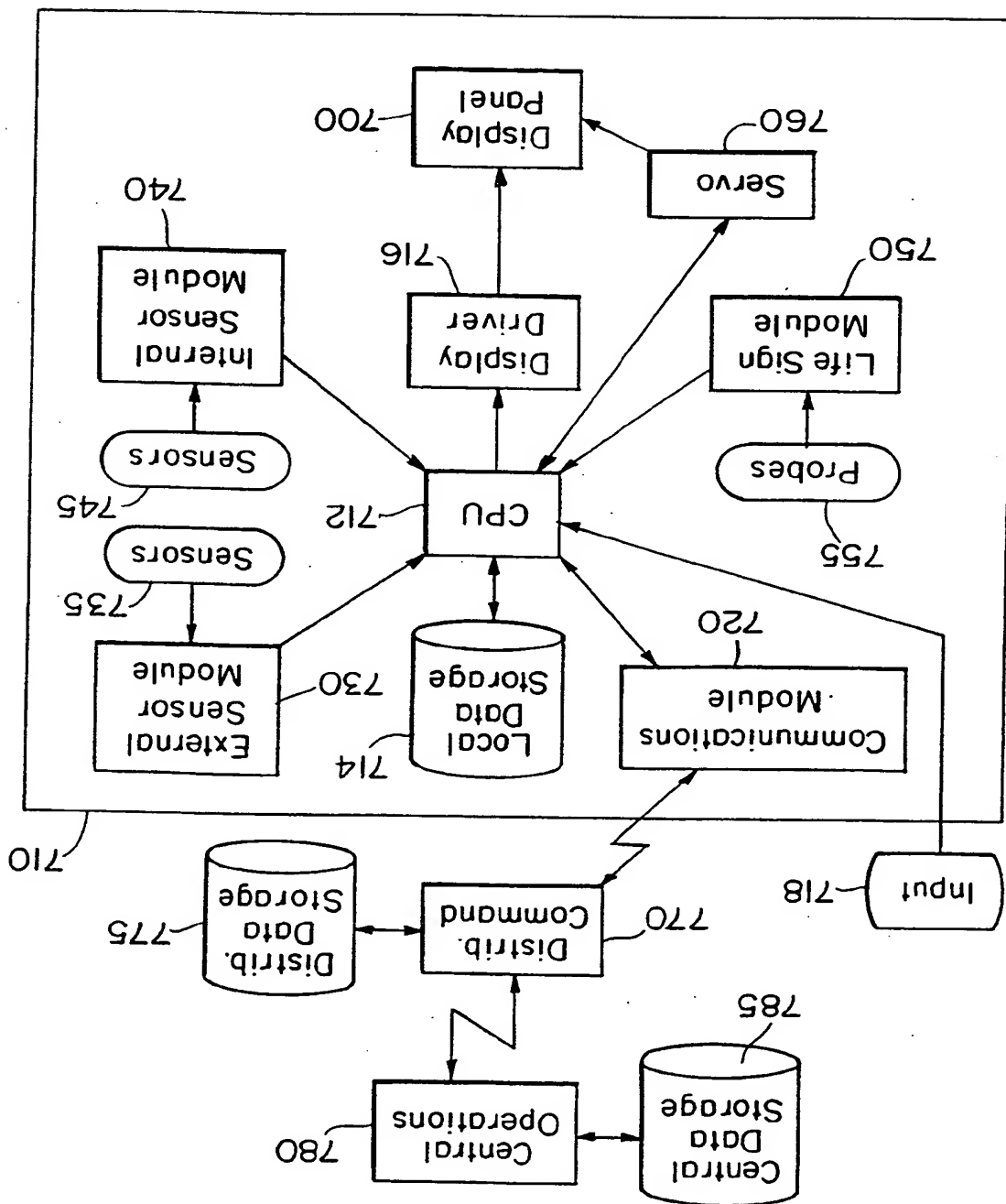


Fig. 34B

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Fig. 35



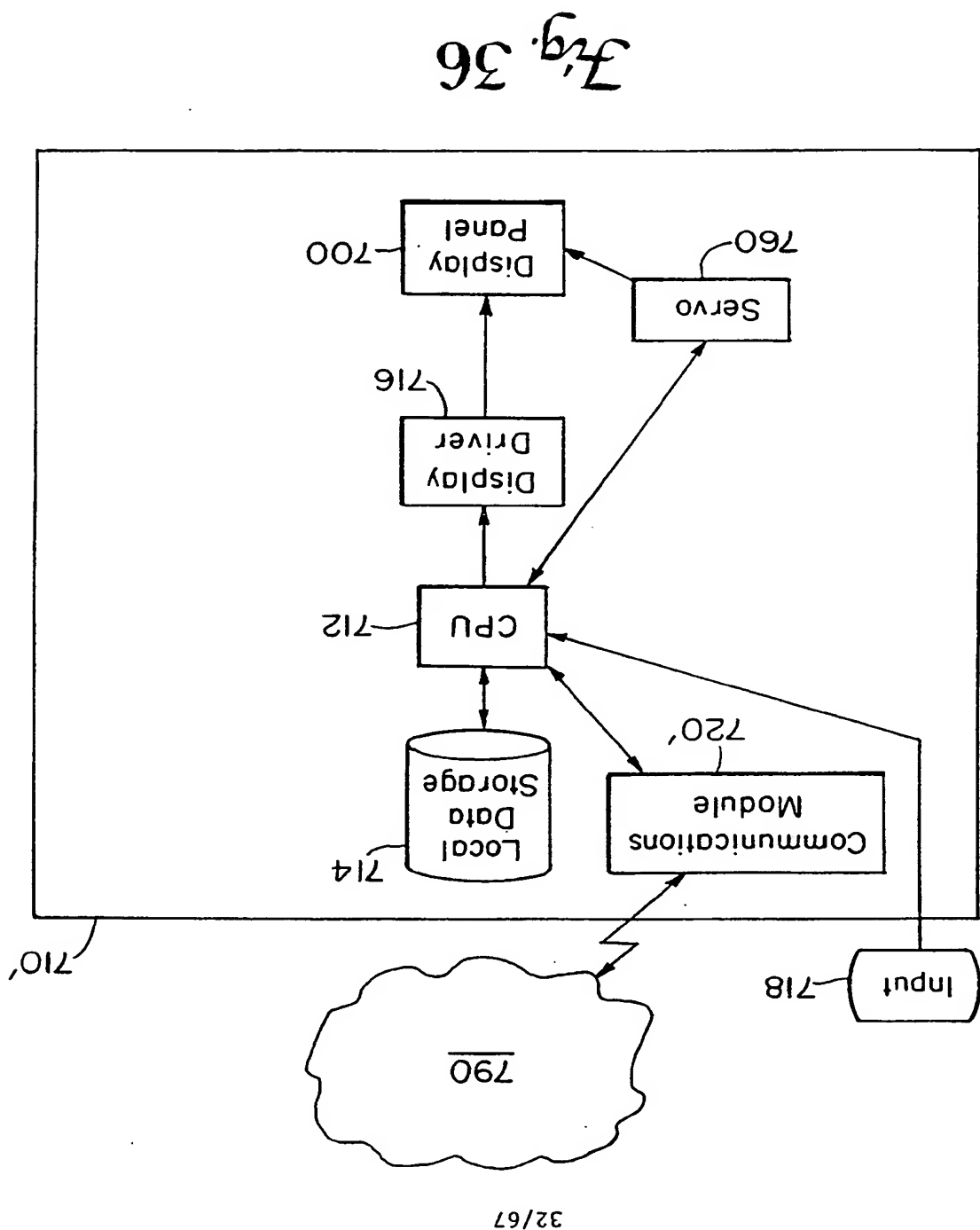
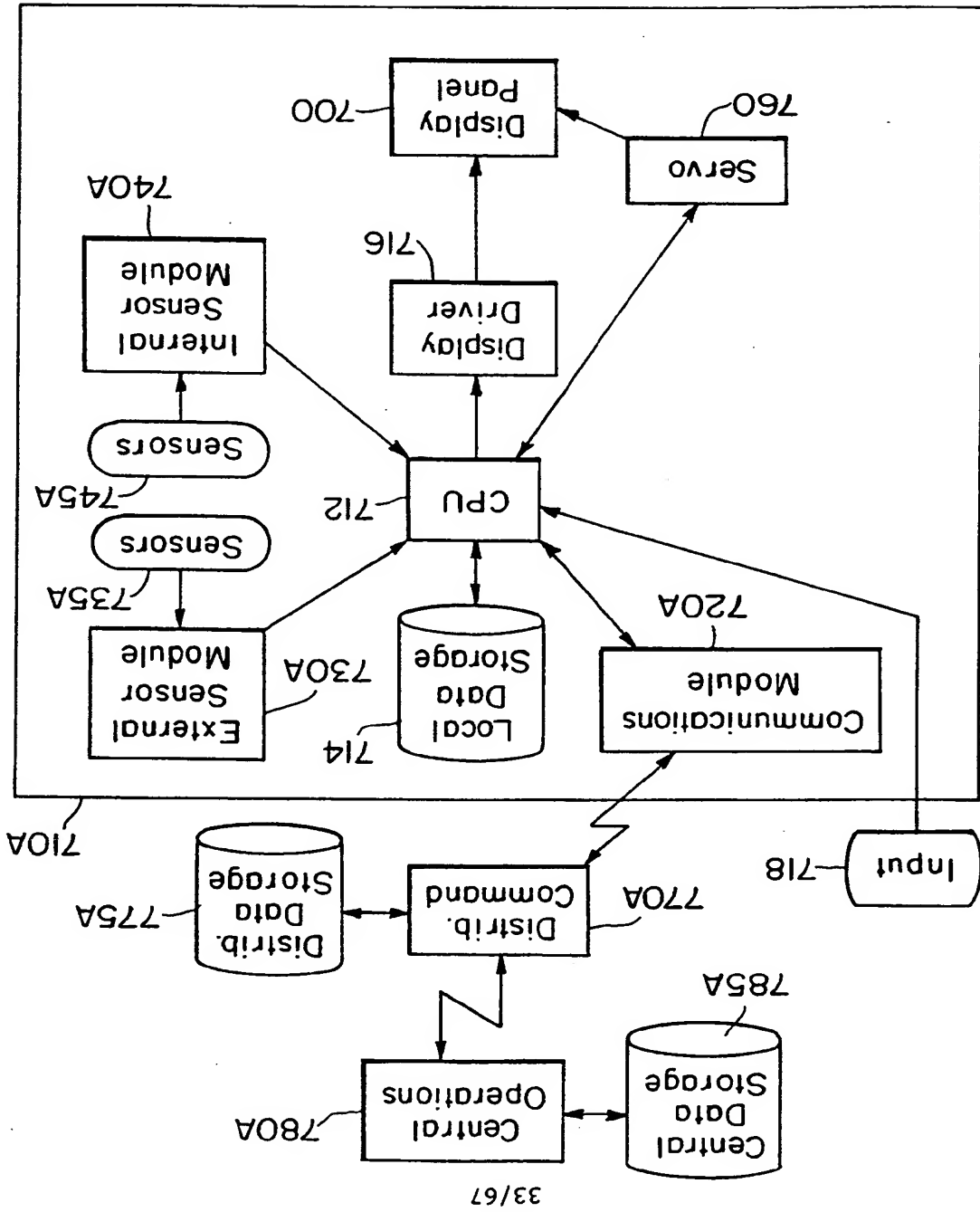


Fig. 37



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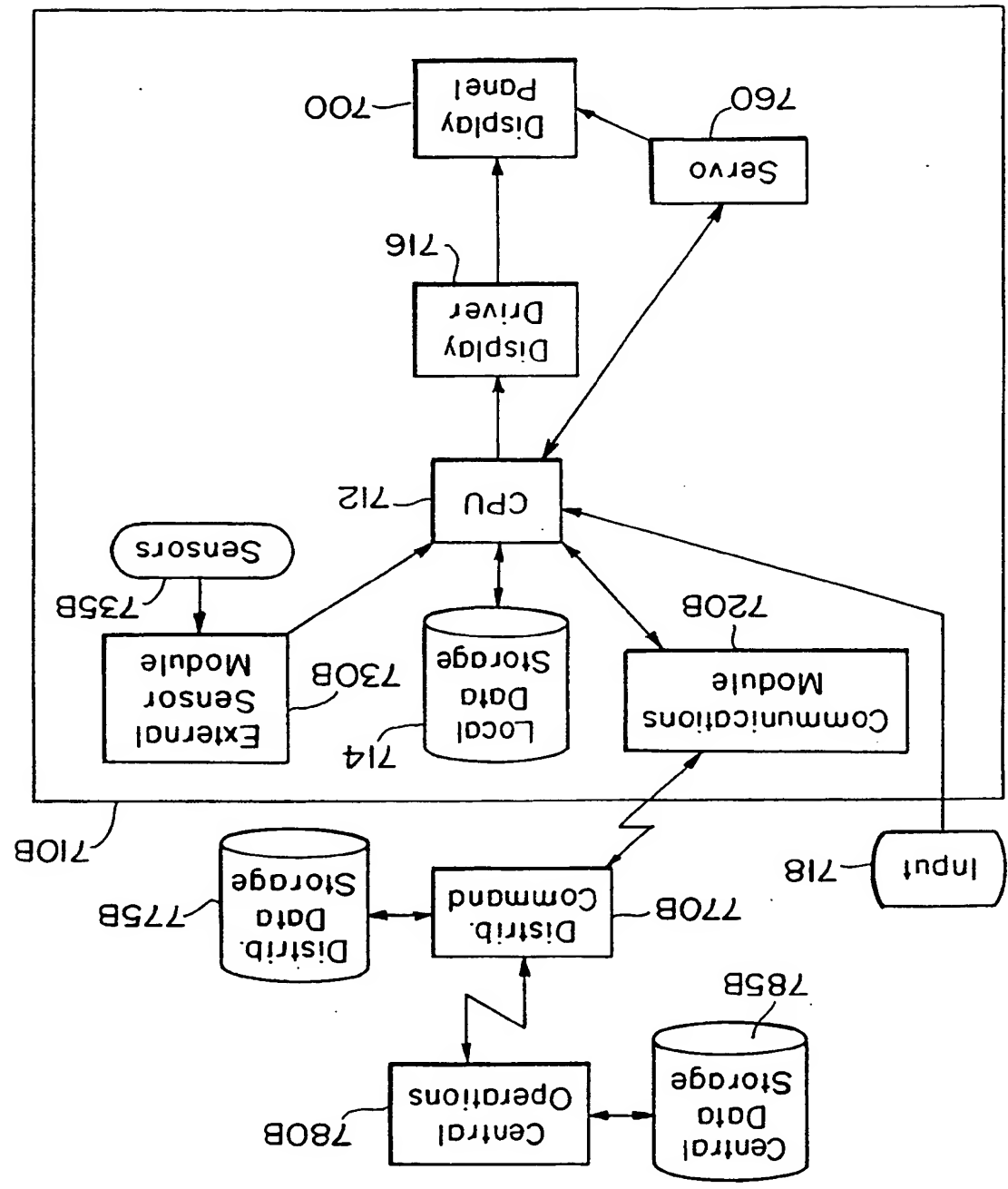
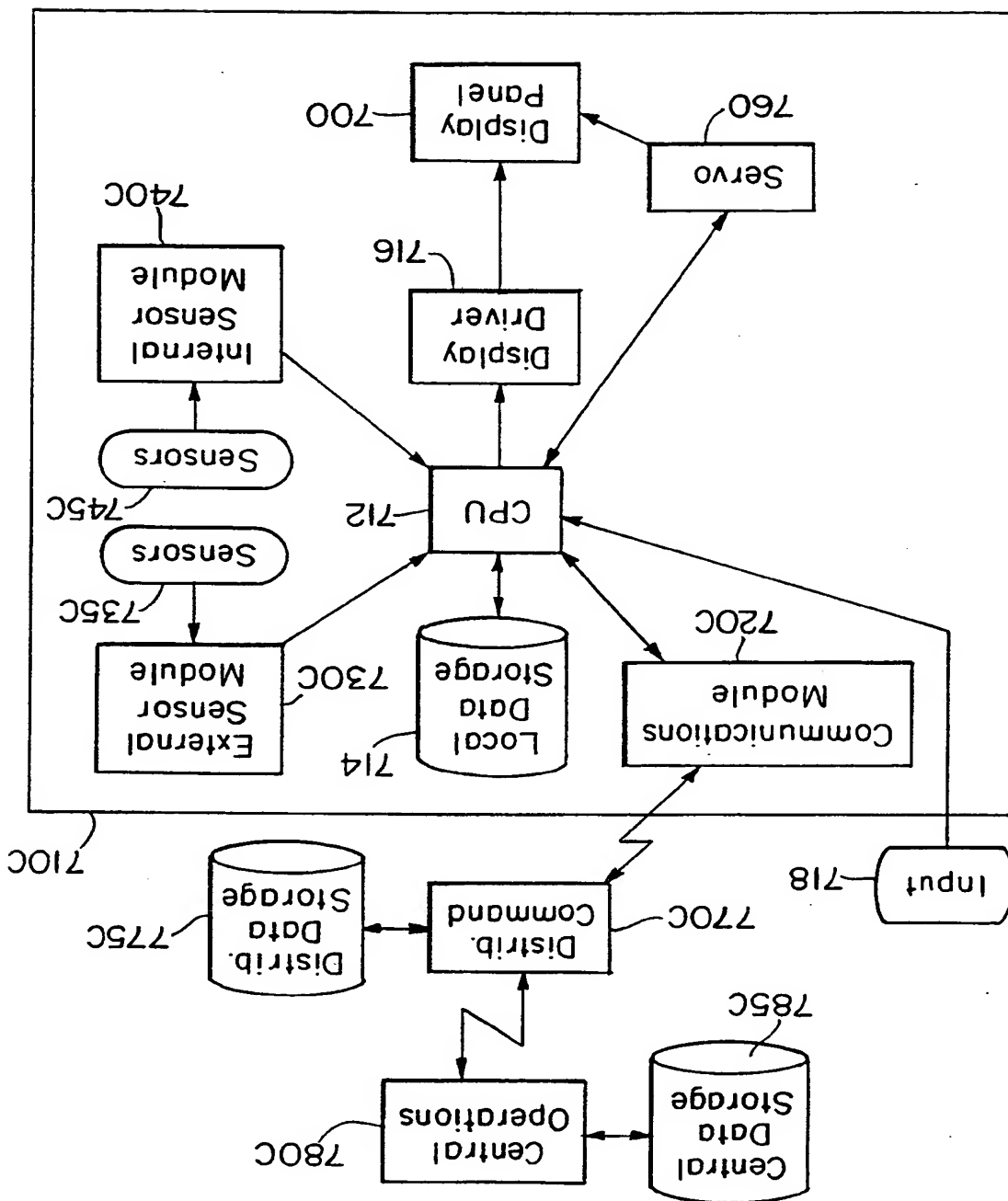


Fig. 38

Fig. 39



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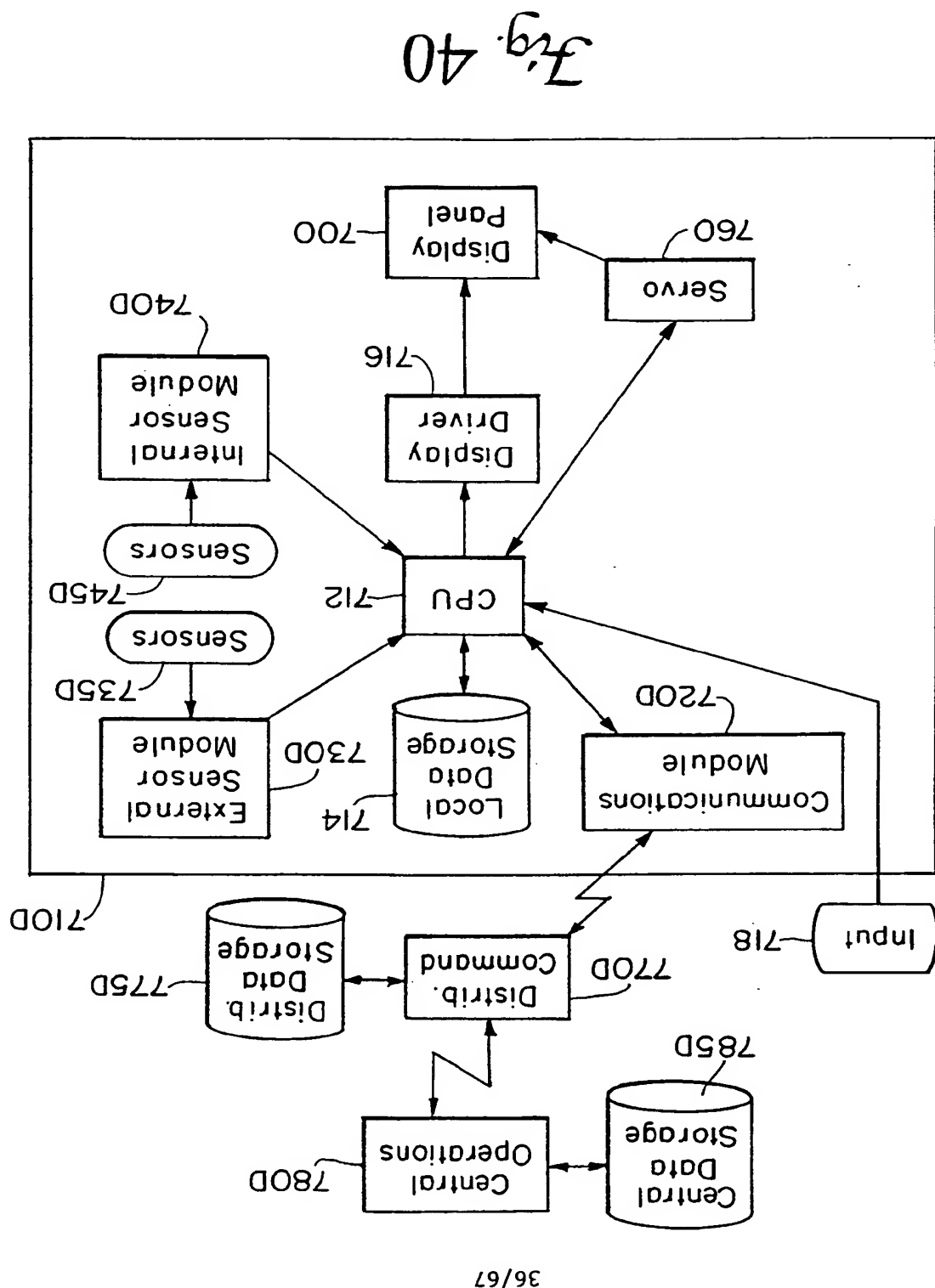
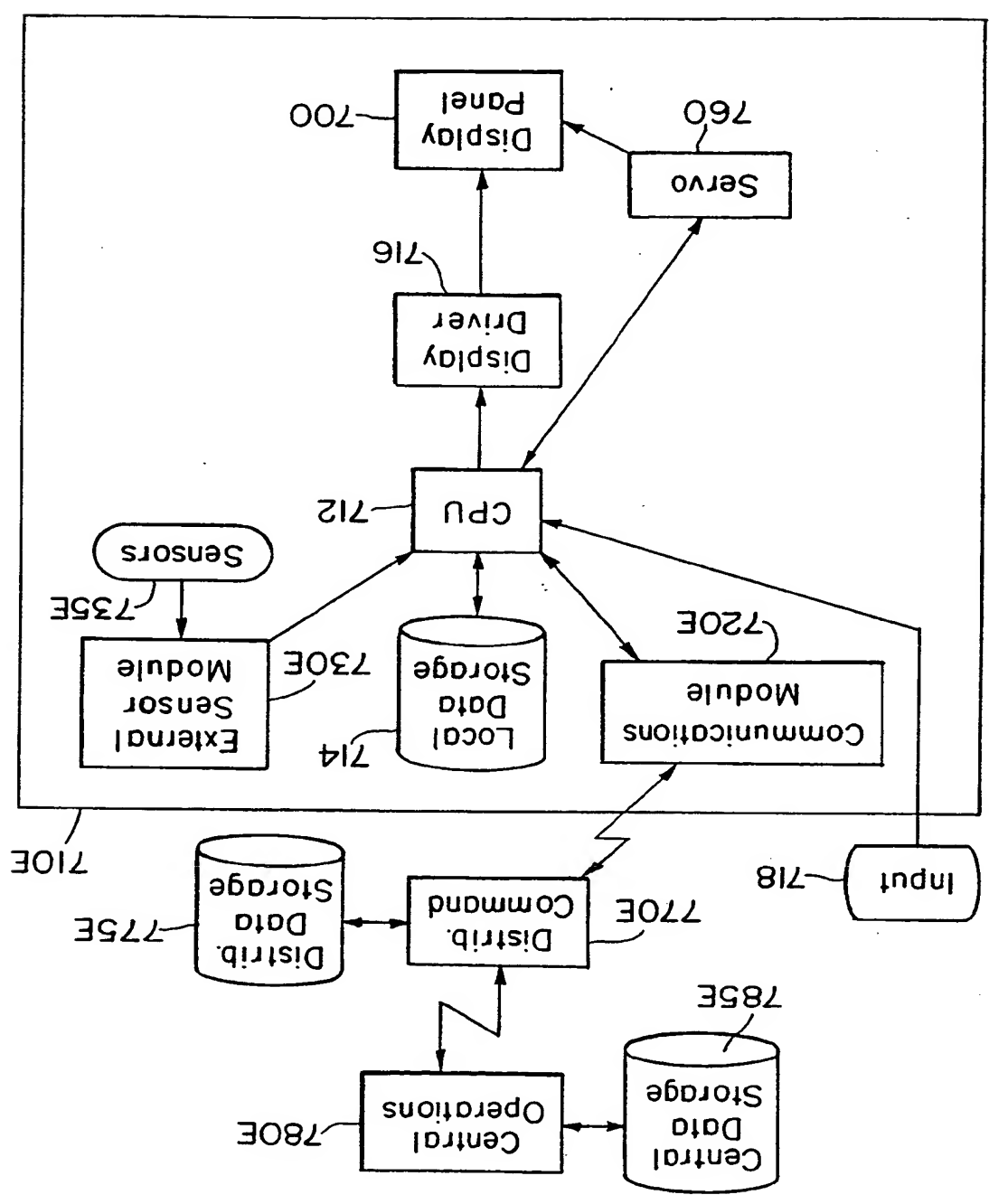


Fig. 41



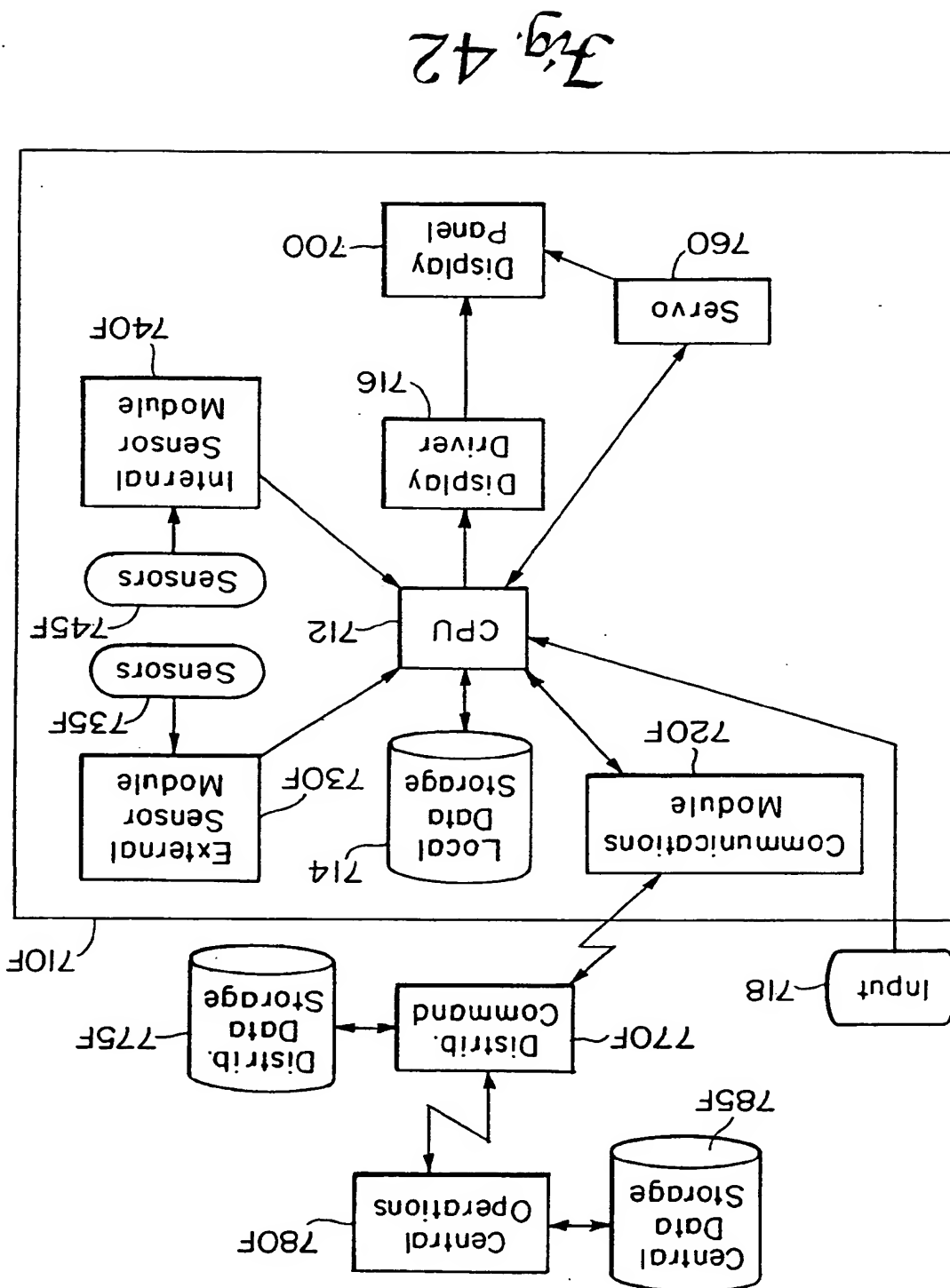
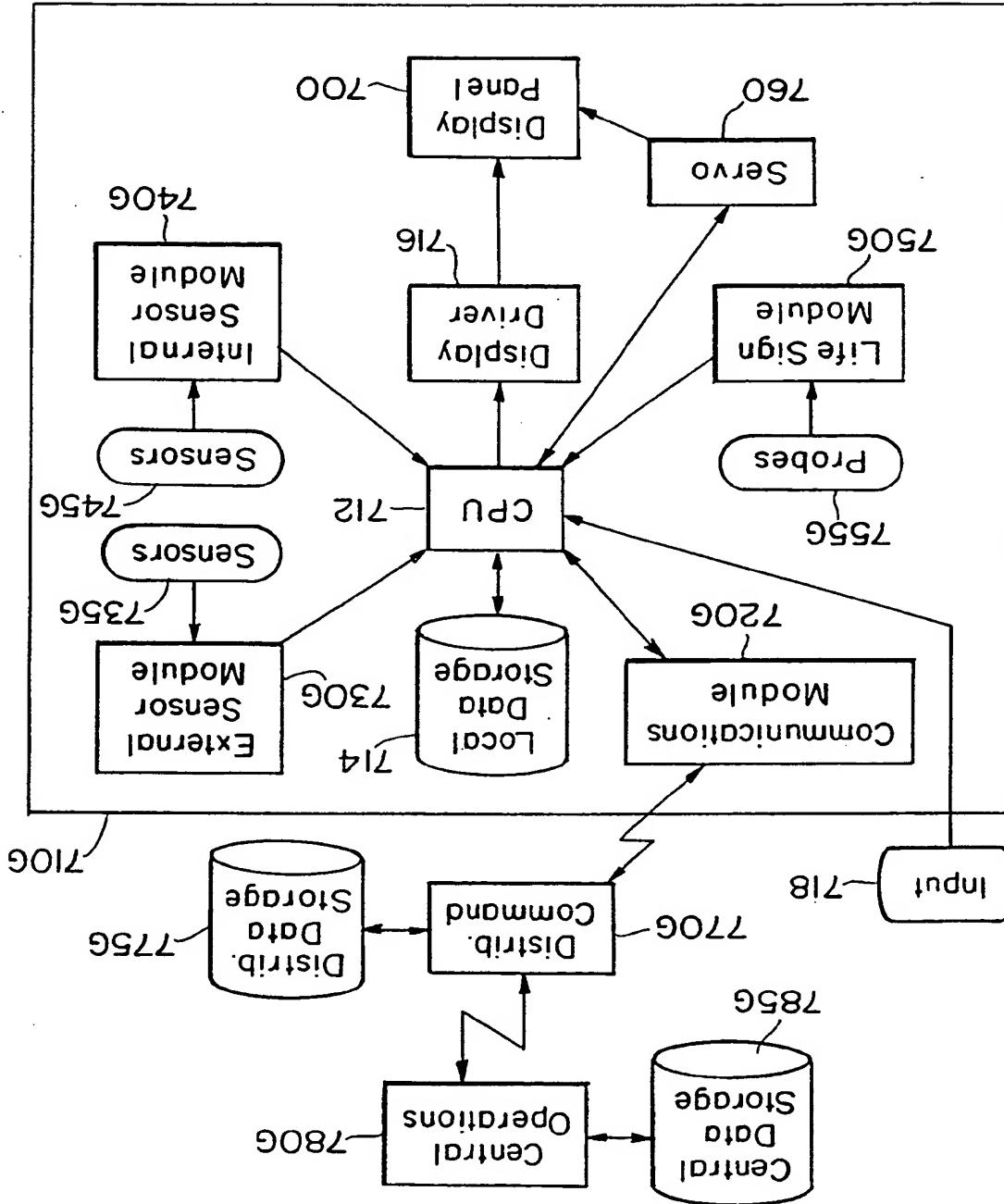
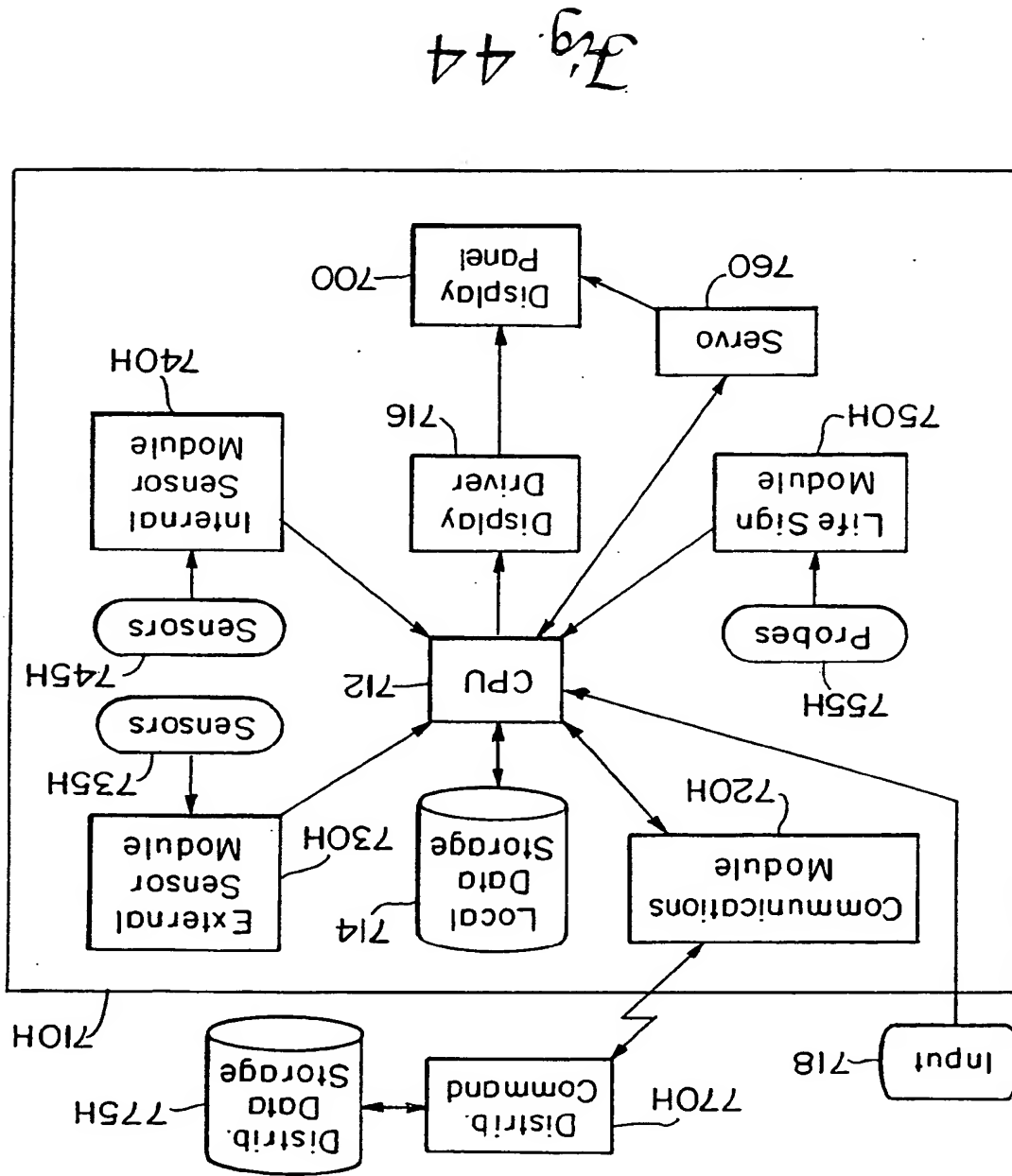
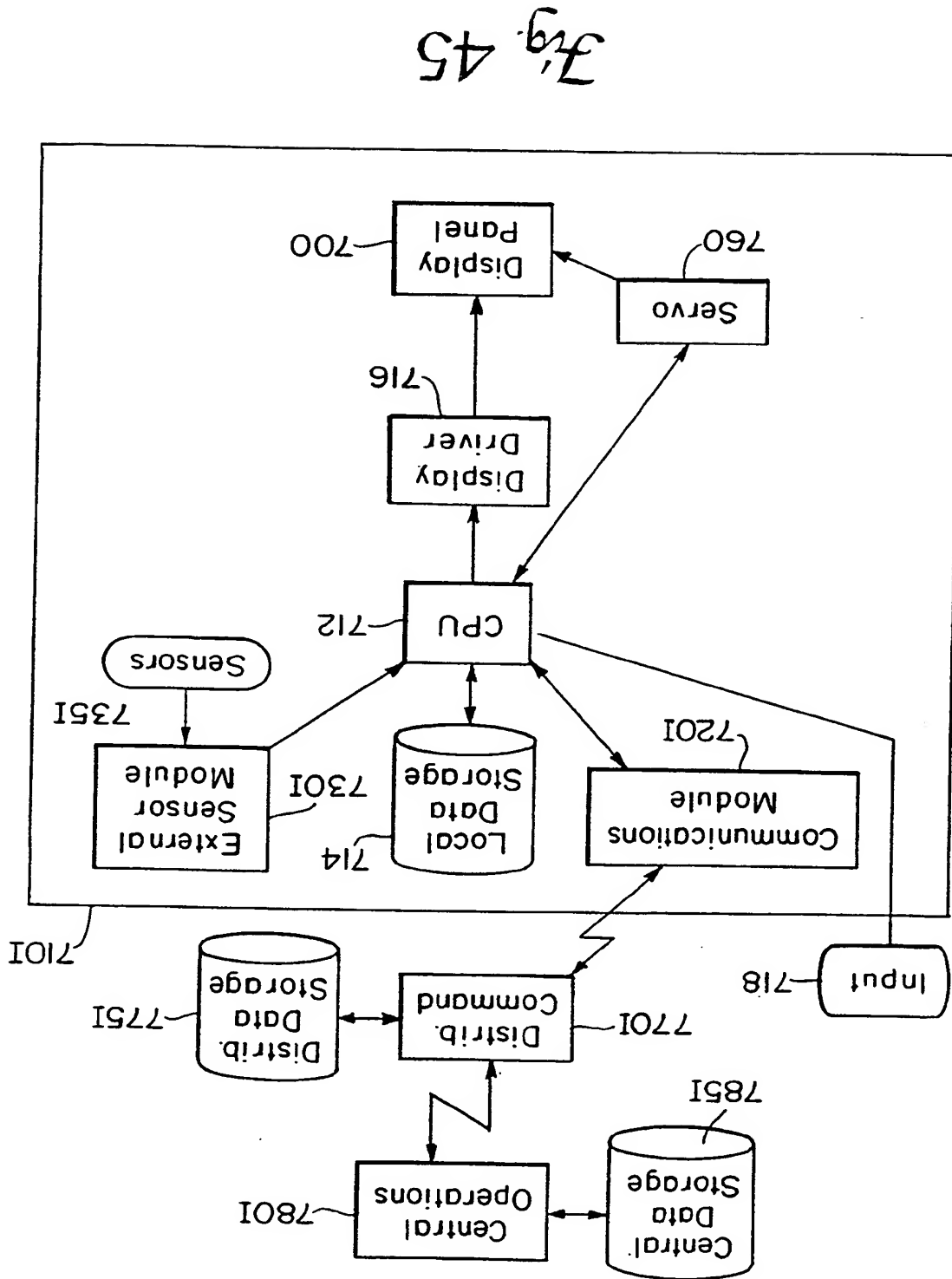


Fig. 43





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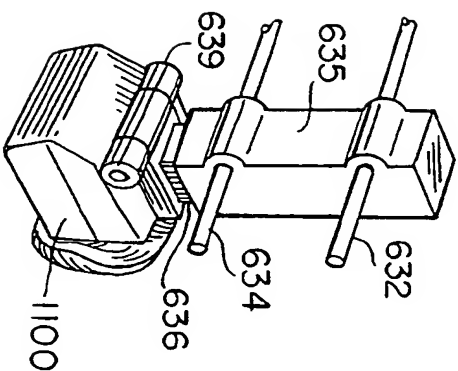


Fig. 46E

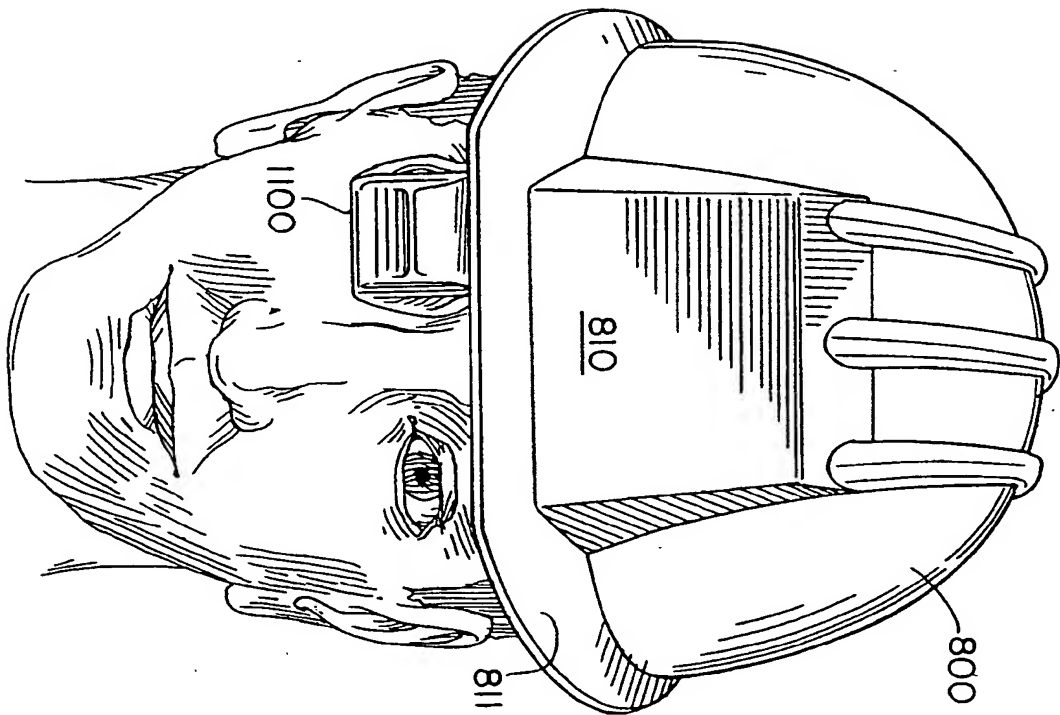


Fig. 46A

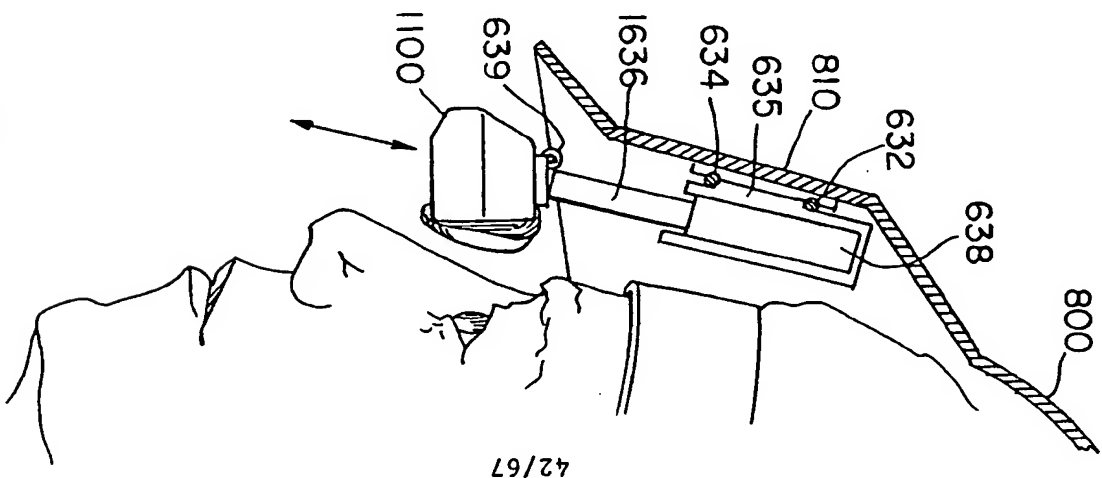
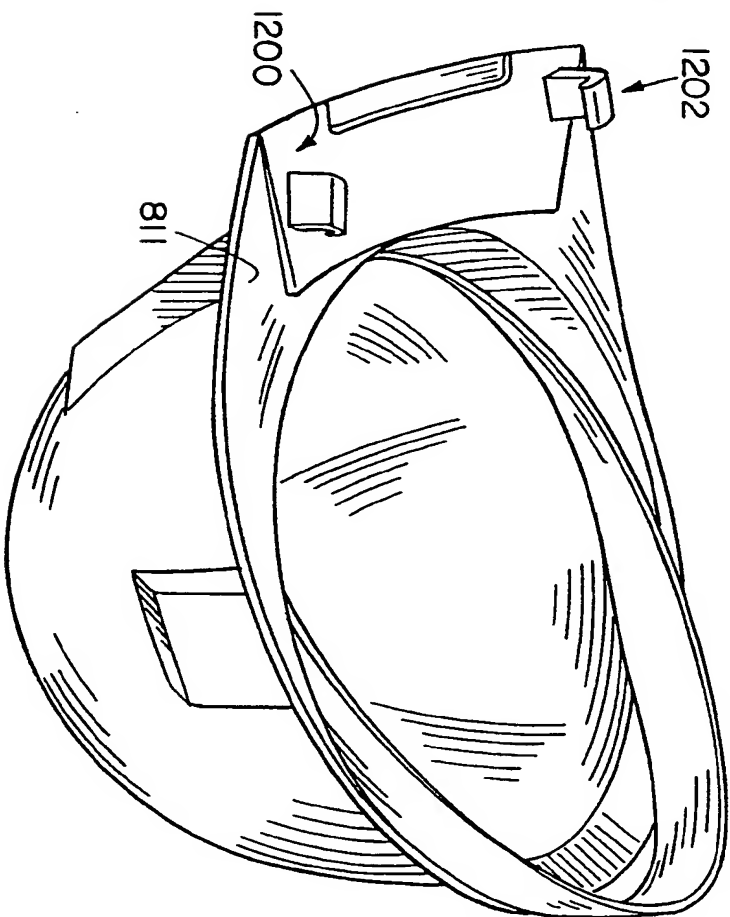
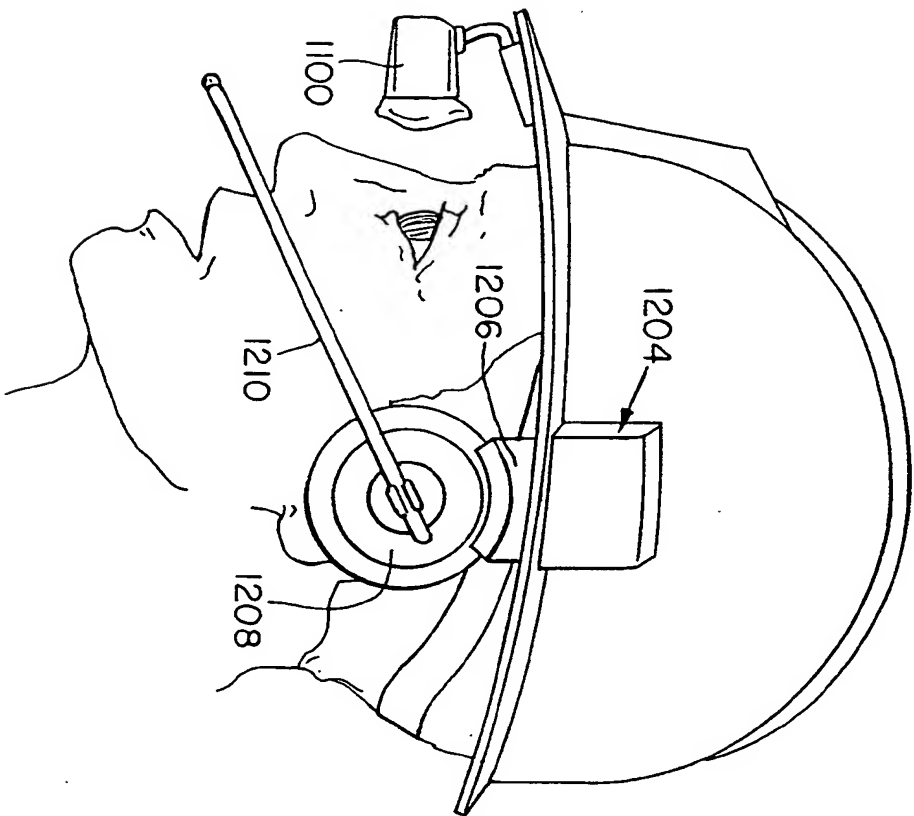
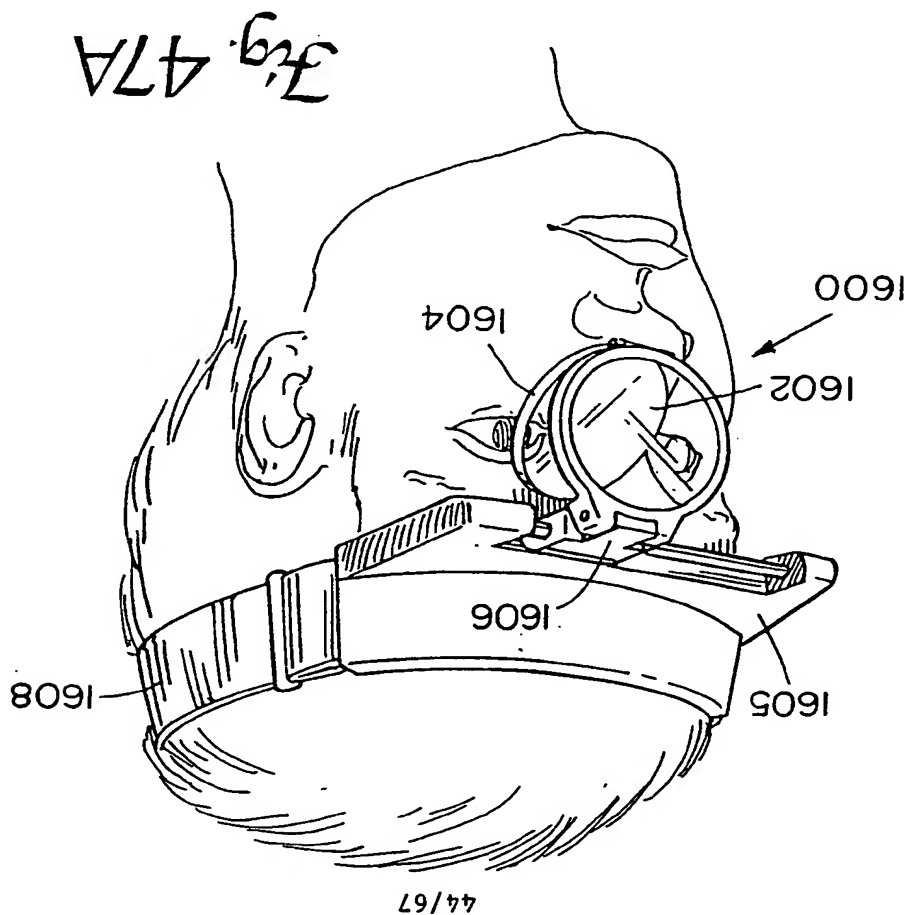
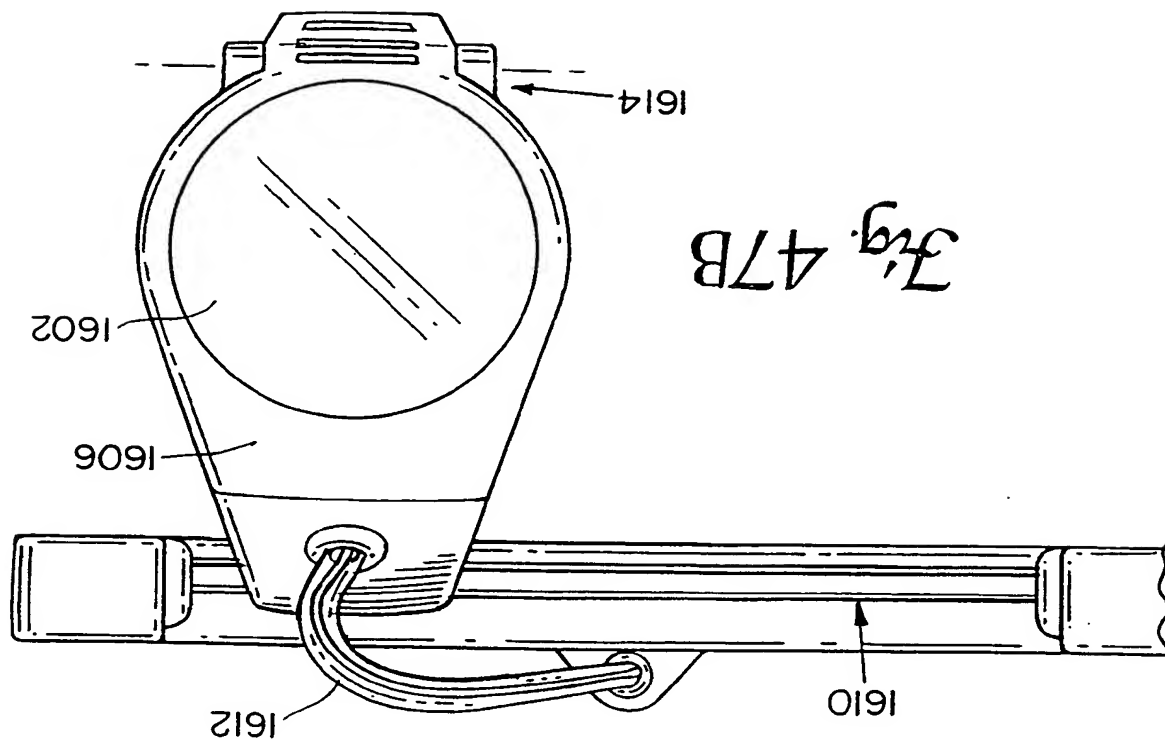


Fig. 46B

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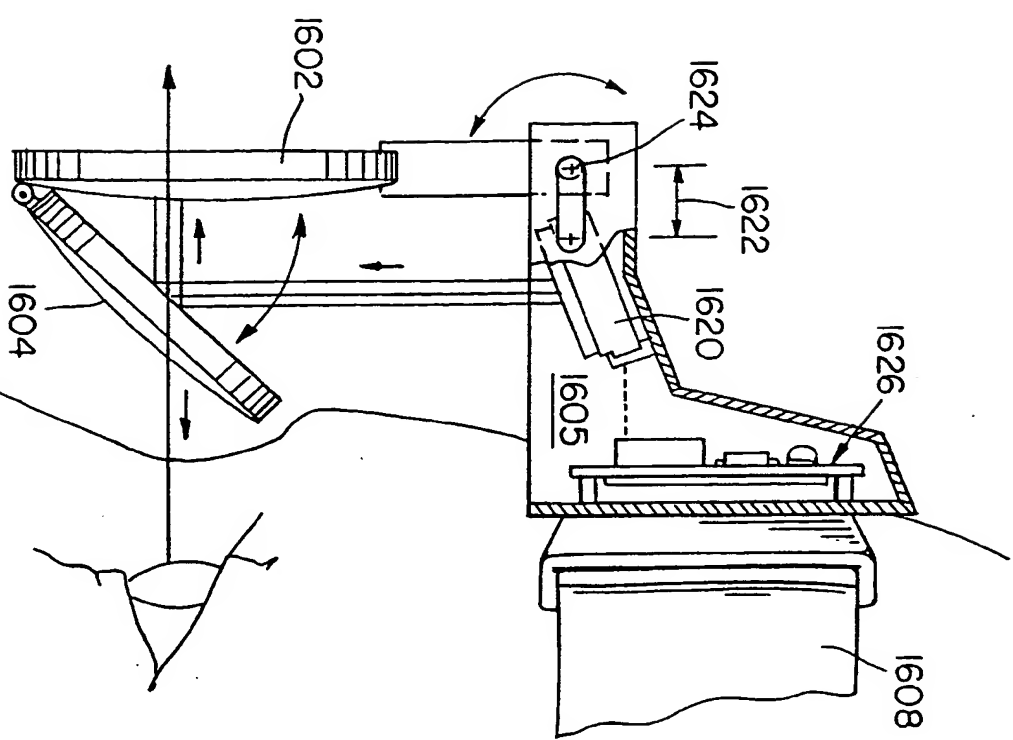


Fig. 47C

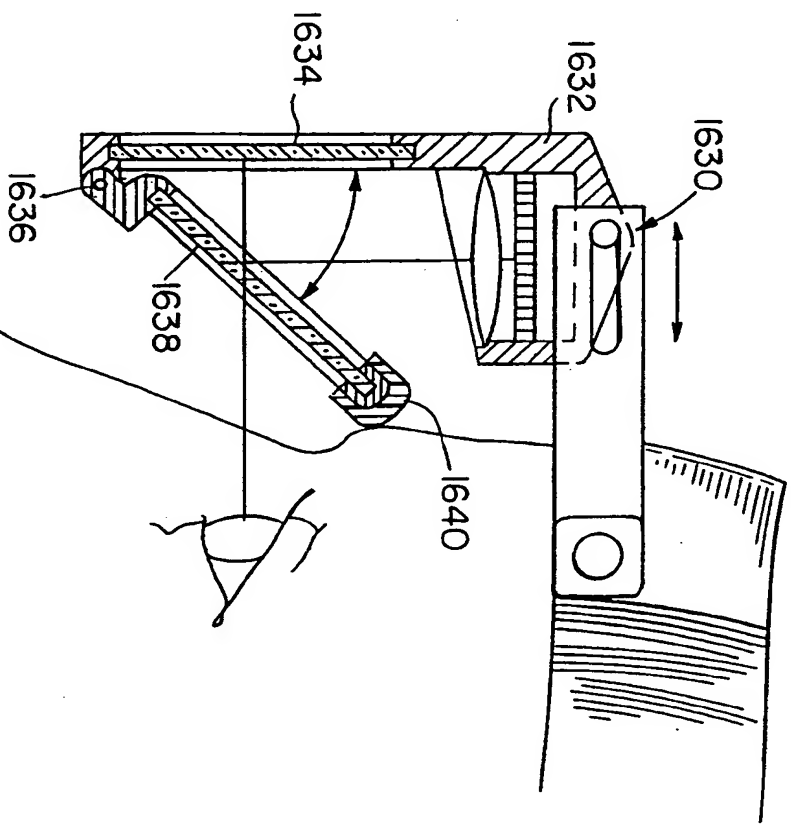


Fig. 47D

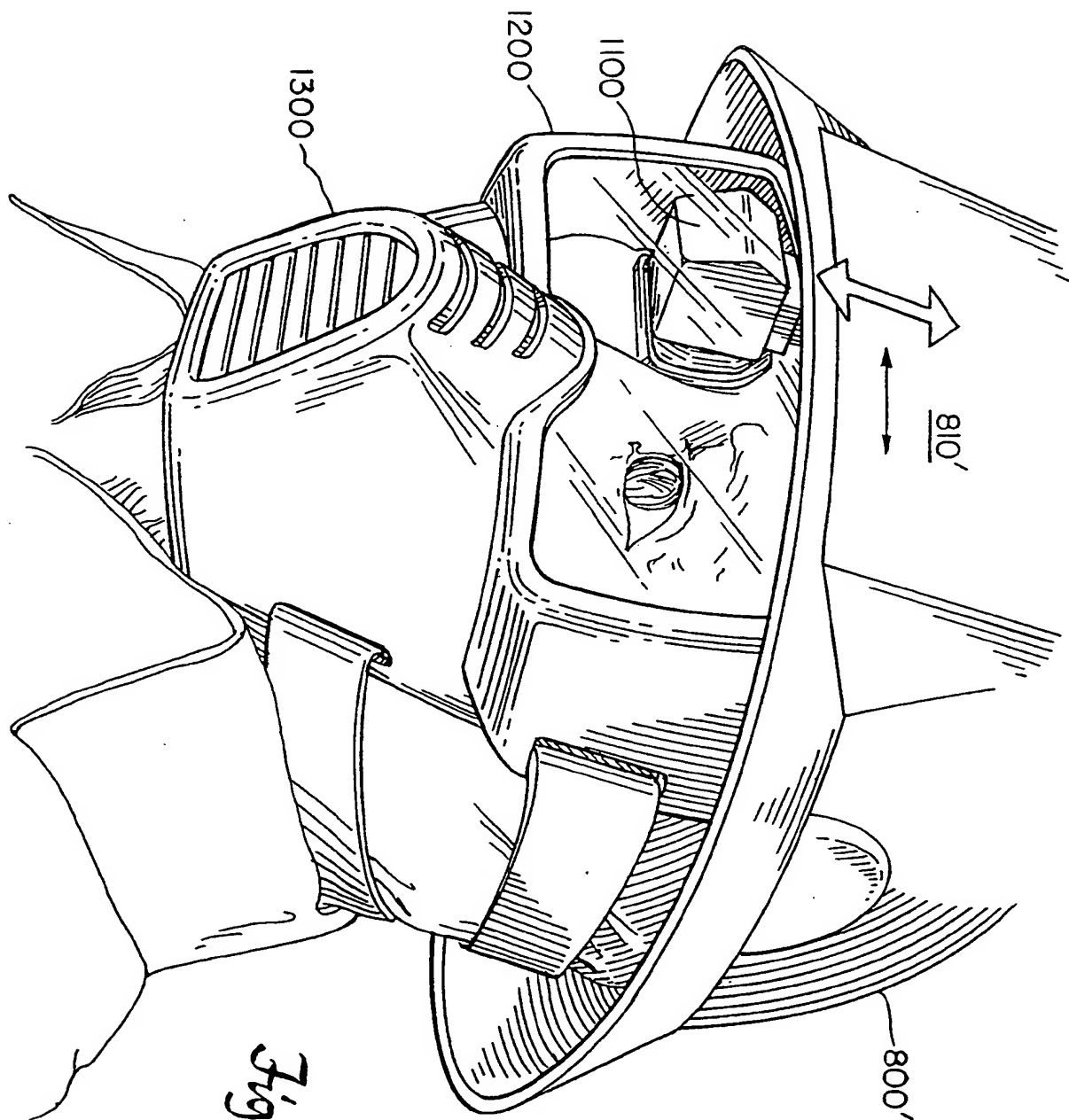


Fig. 48

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Fig. 49

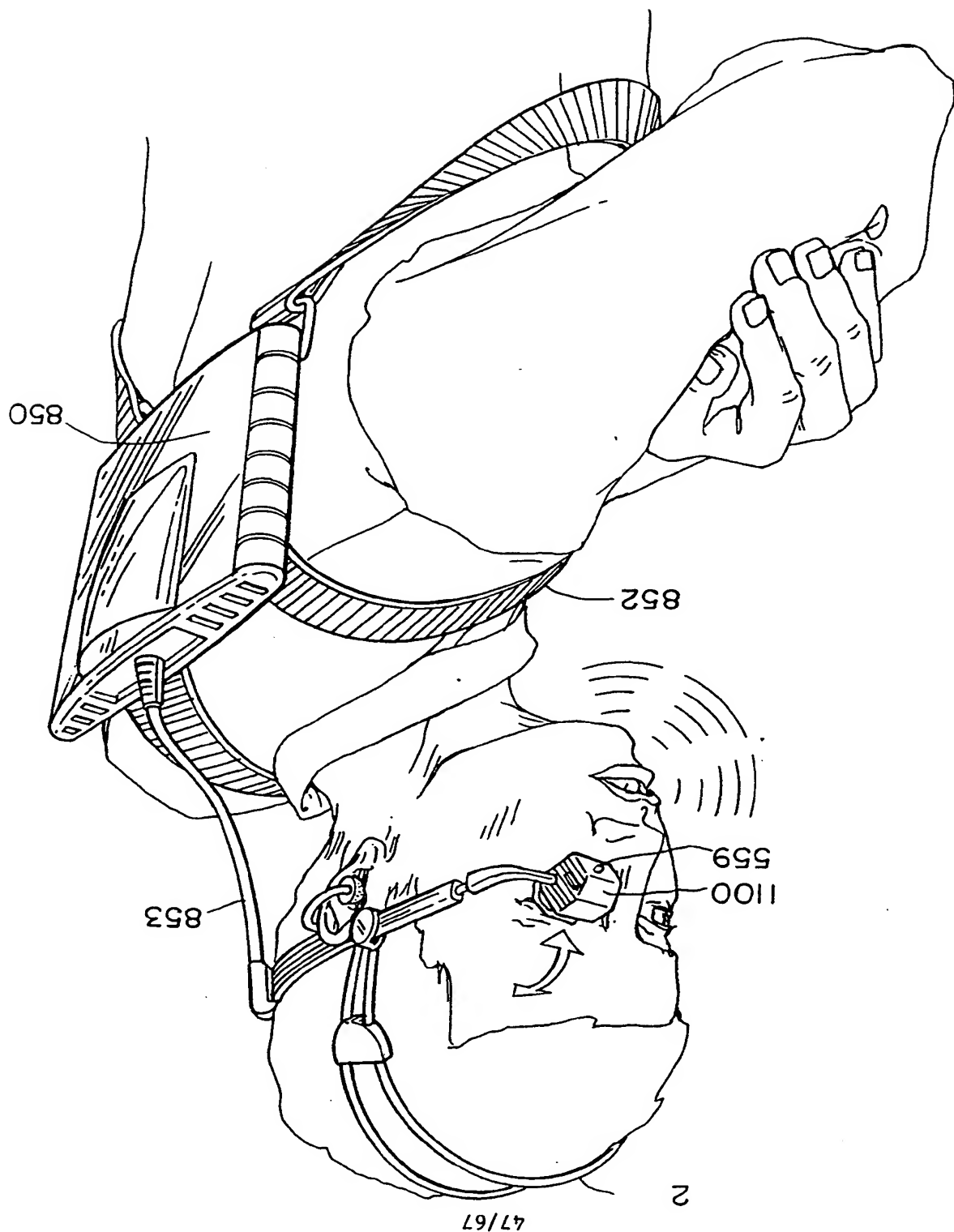
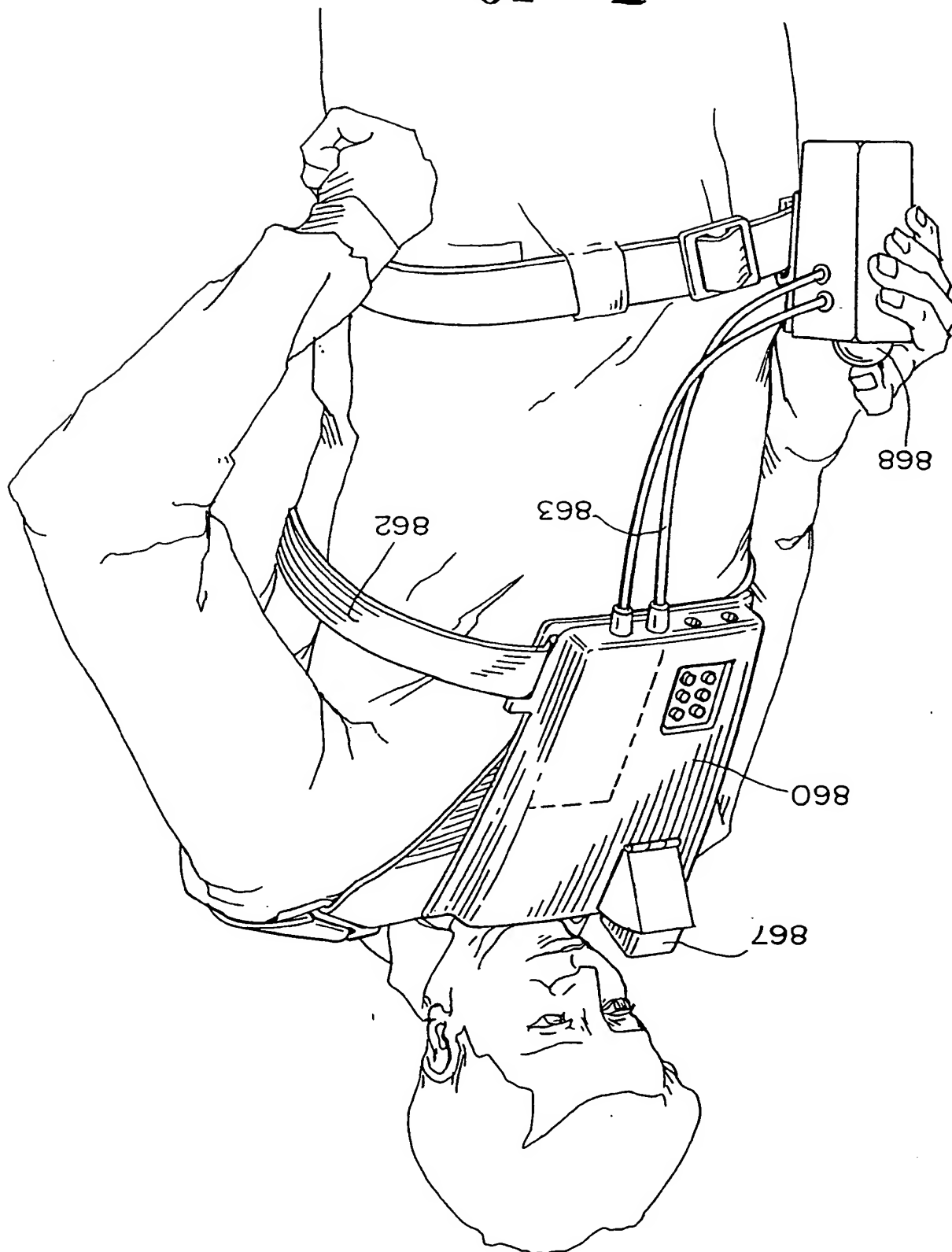
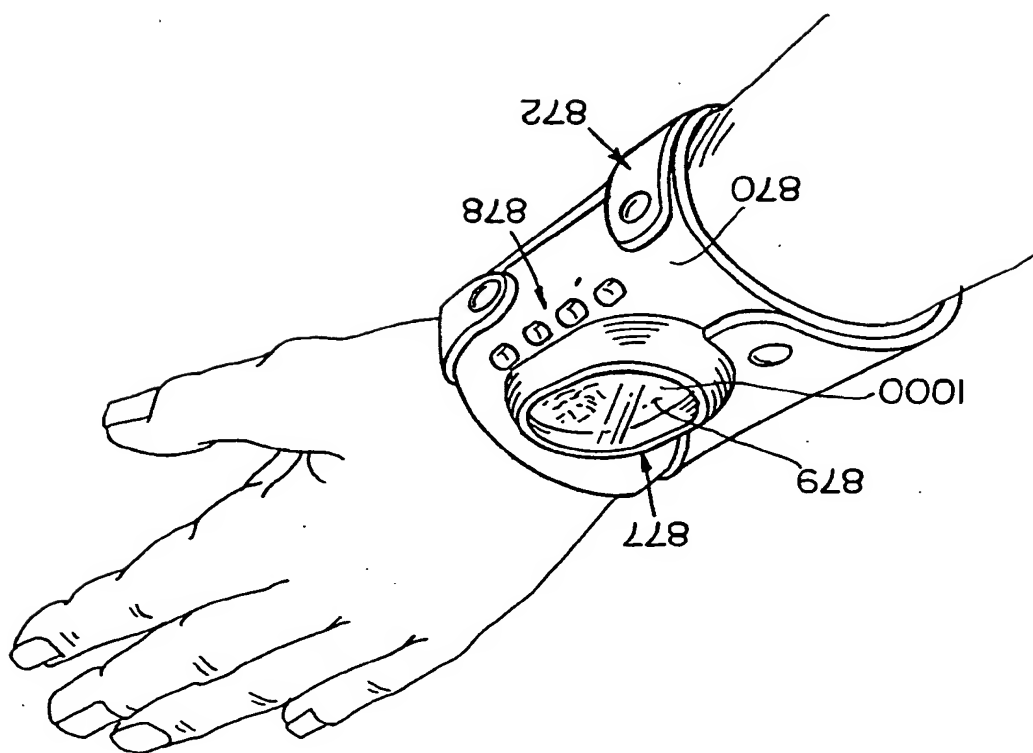


Fig. 50

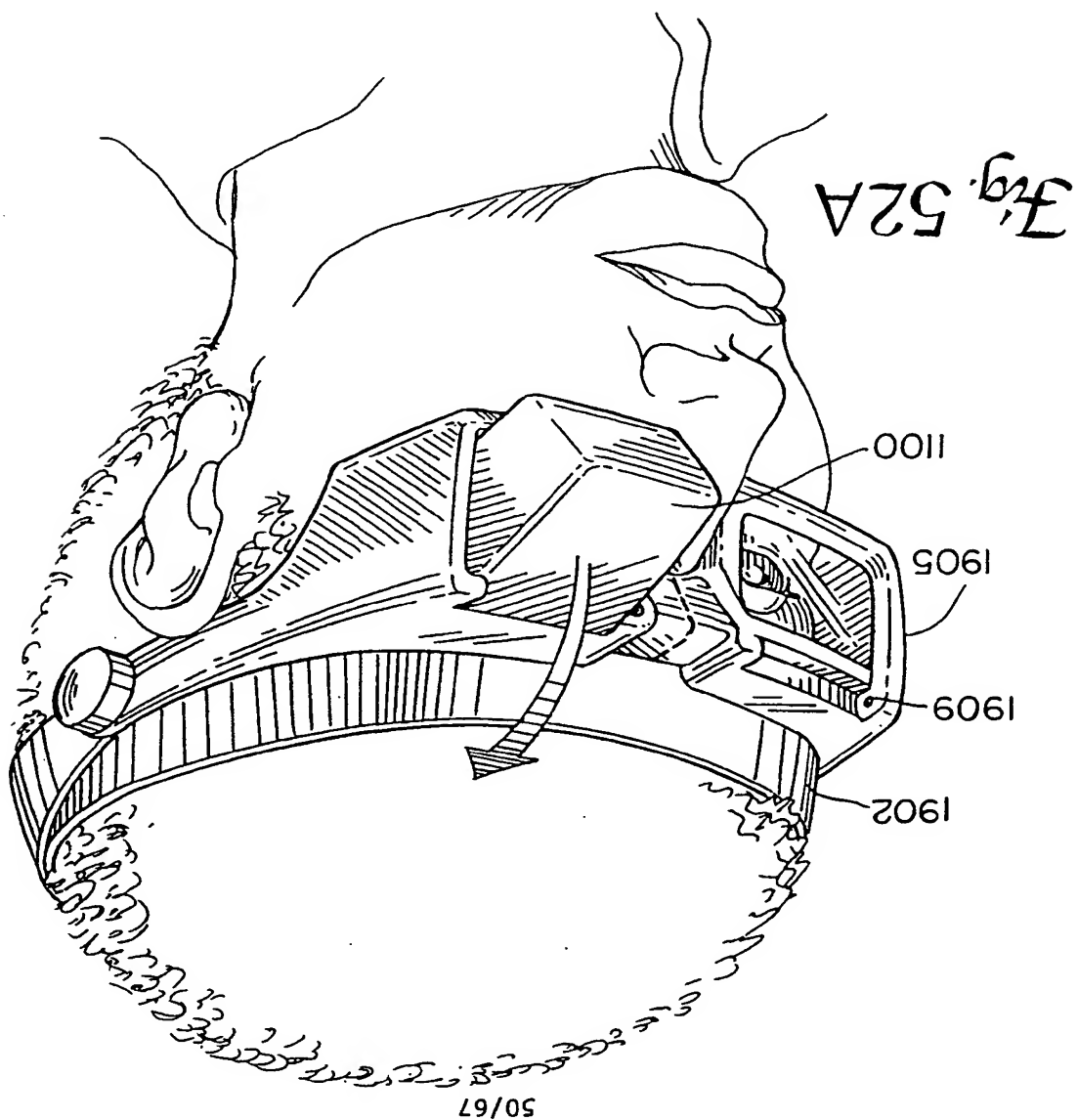
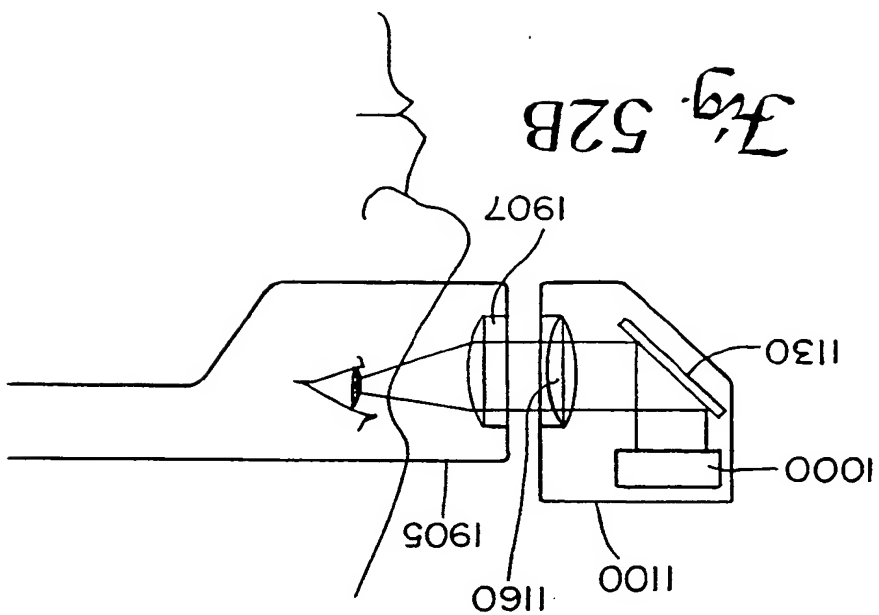


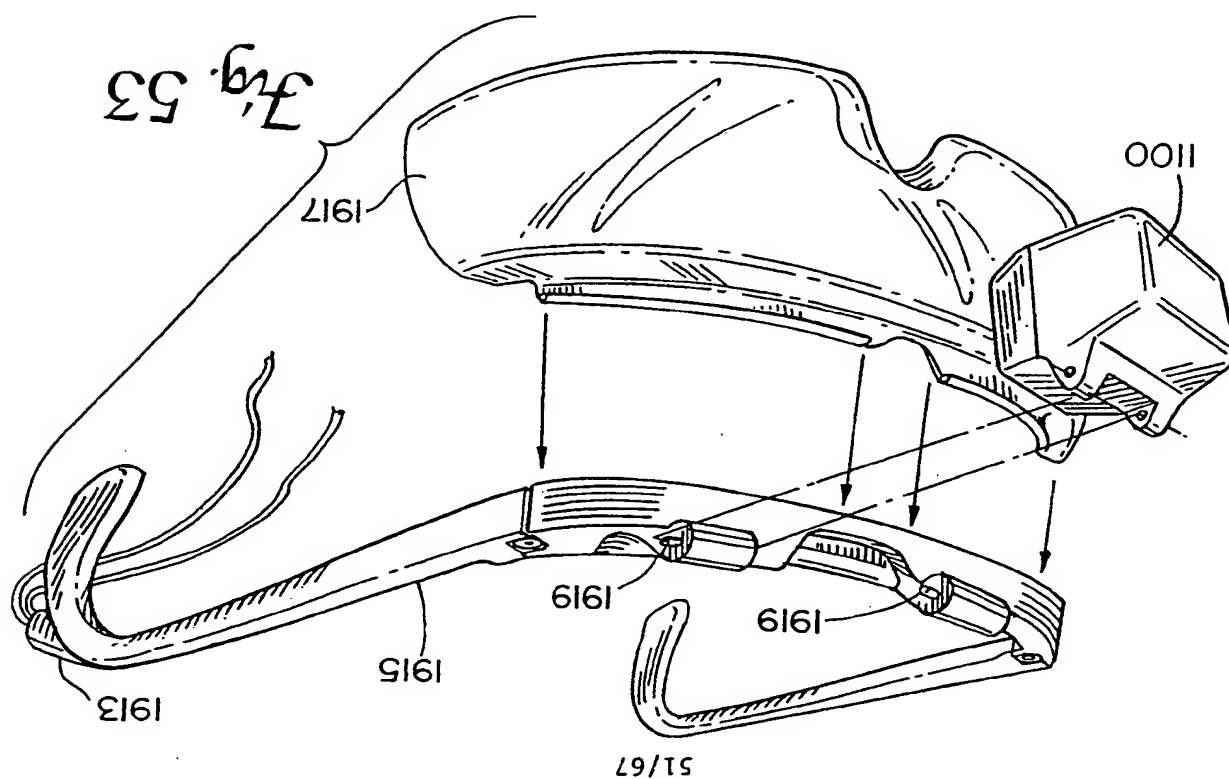
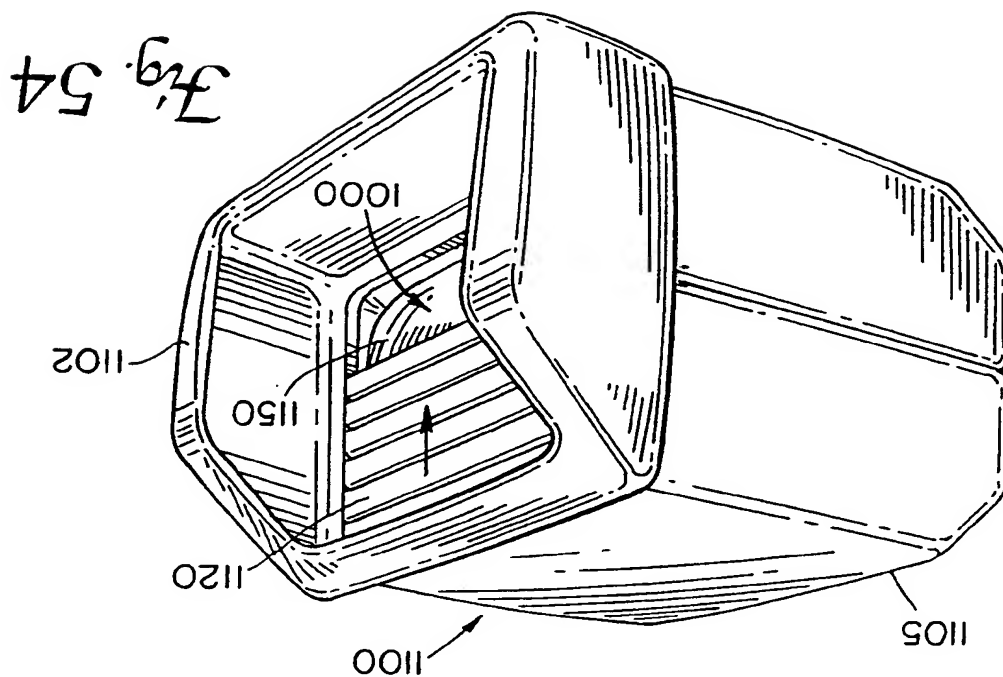
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Fig. 51



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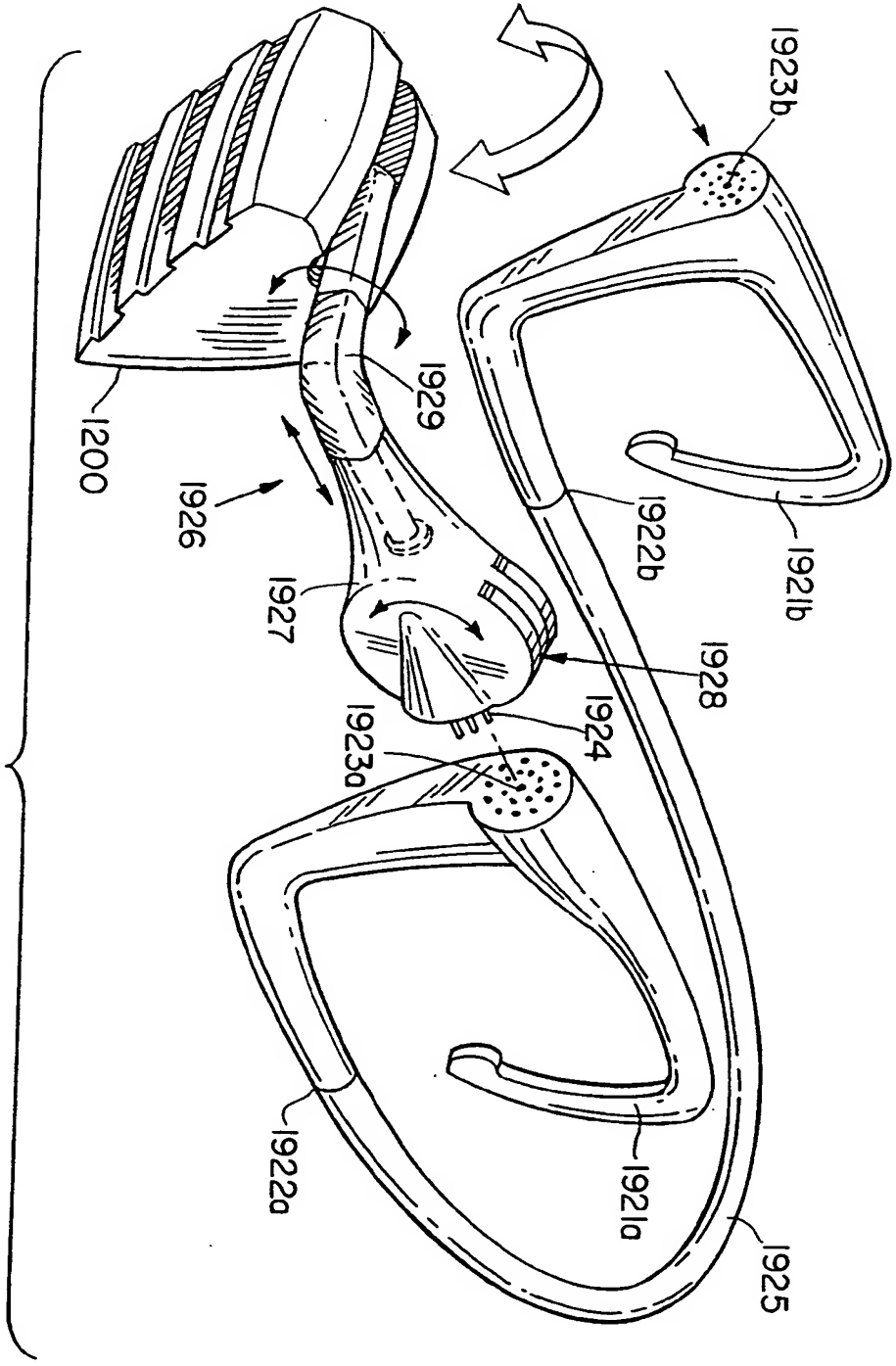


Fig. 55

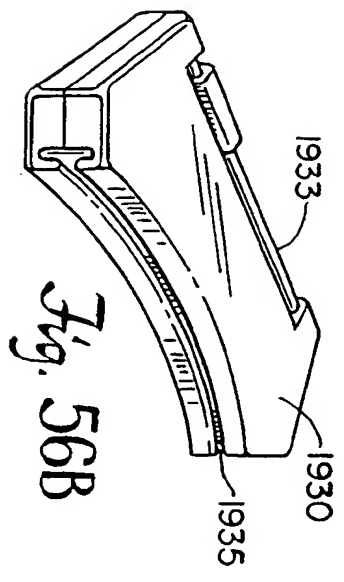


Fig. 56B

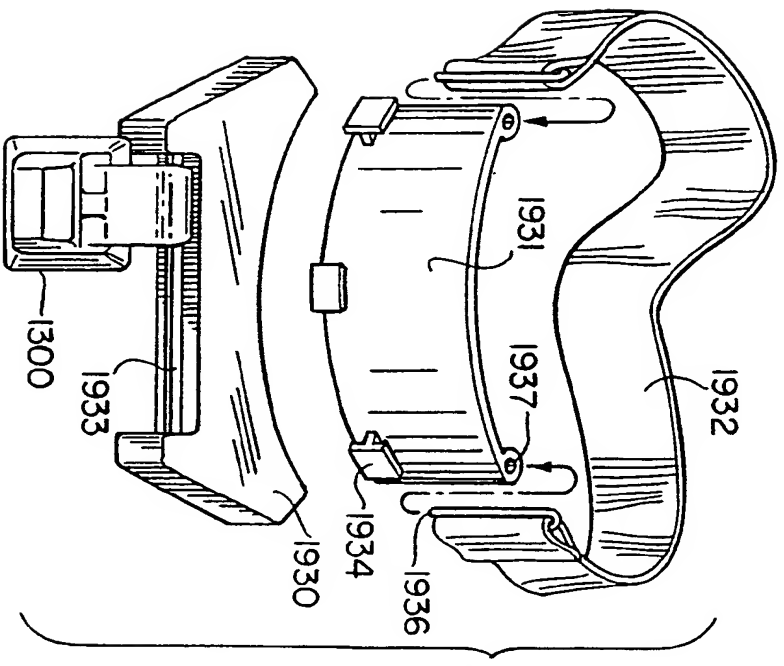


Fig. 56A

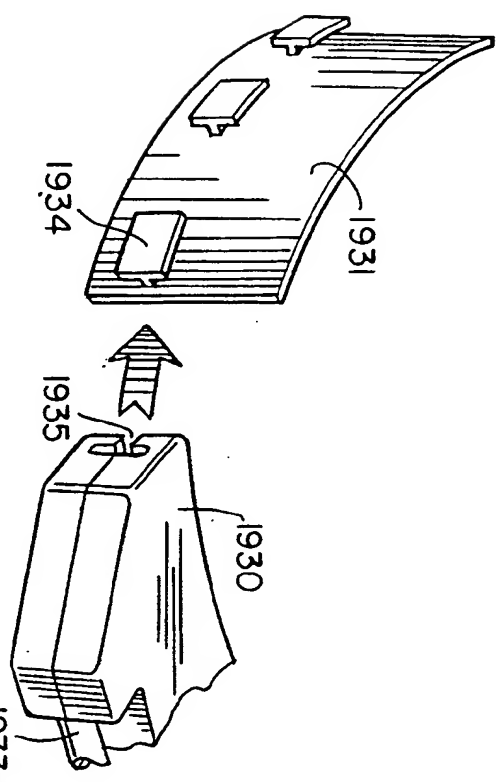


Fig. 56C

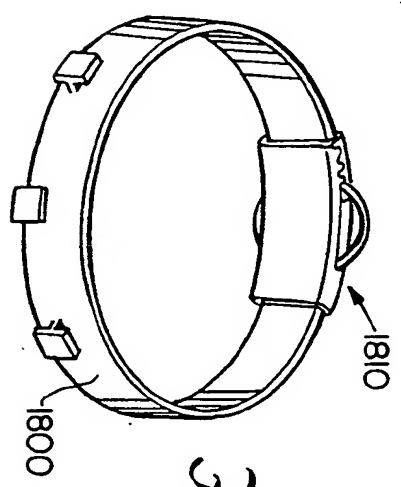


Fig. 56D

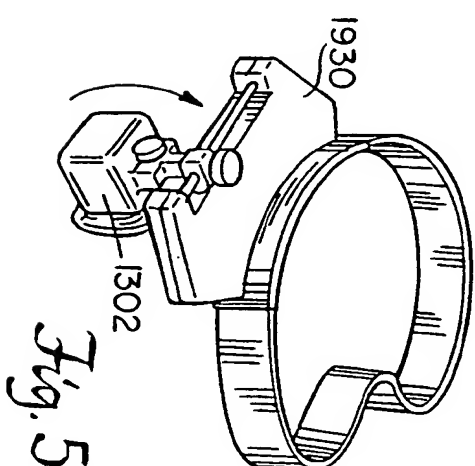
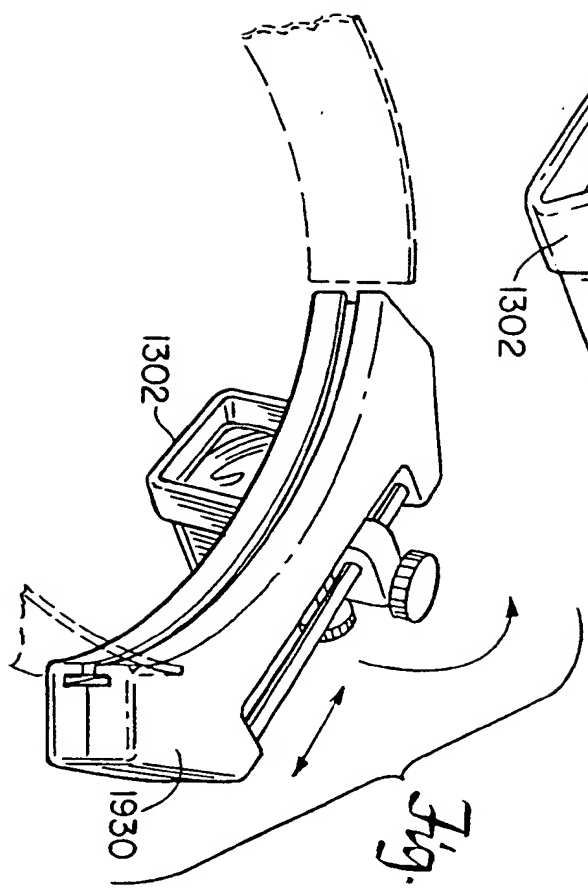
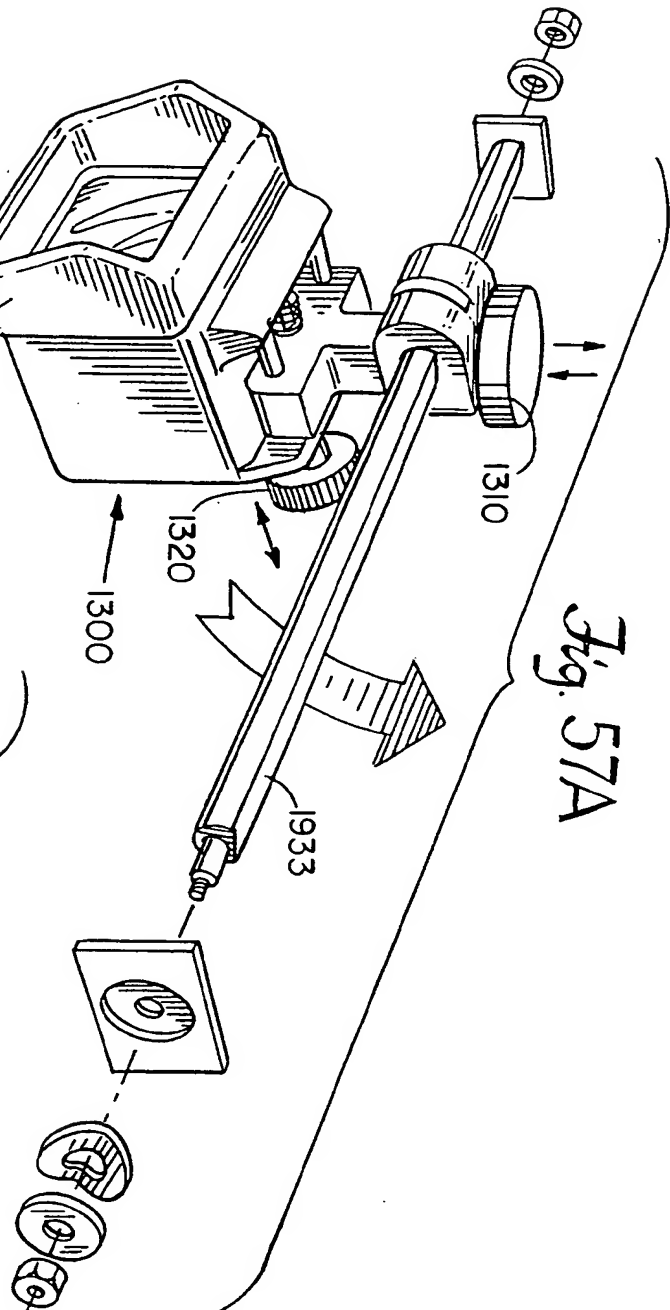


Fig. 57D

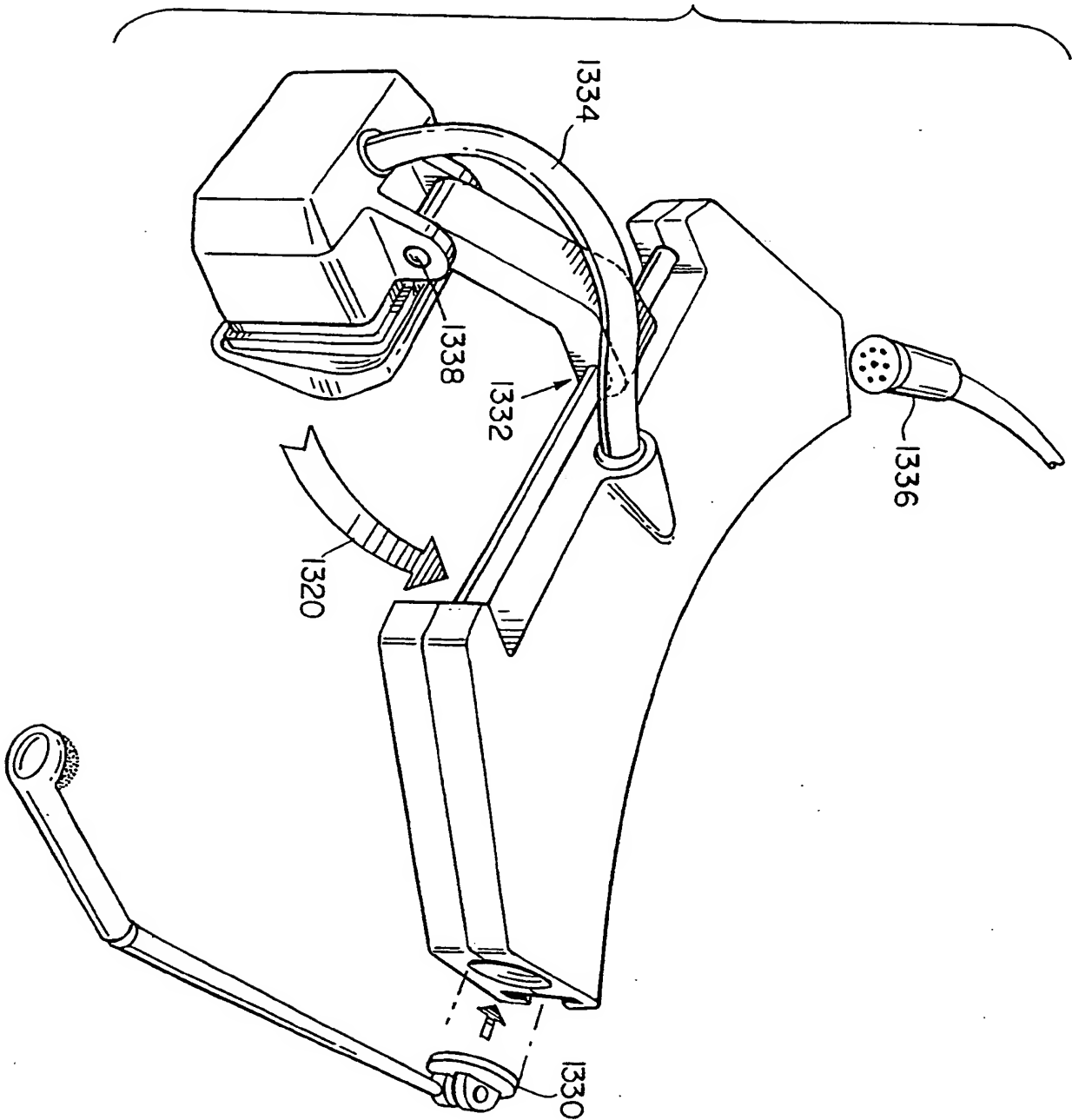


Fig. 57E

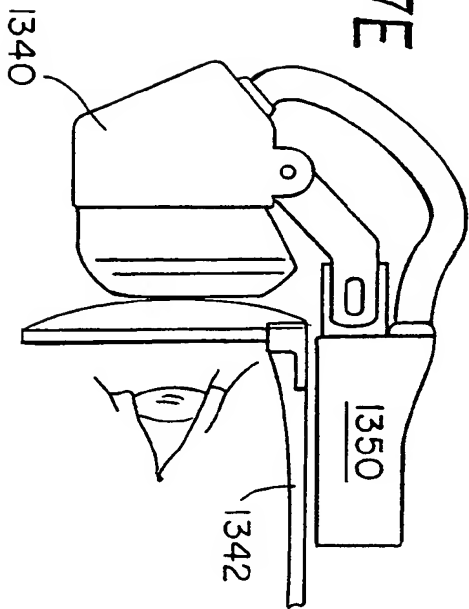


Fig. 57G

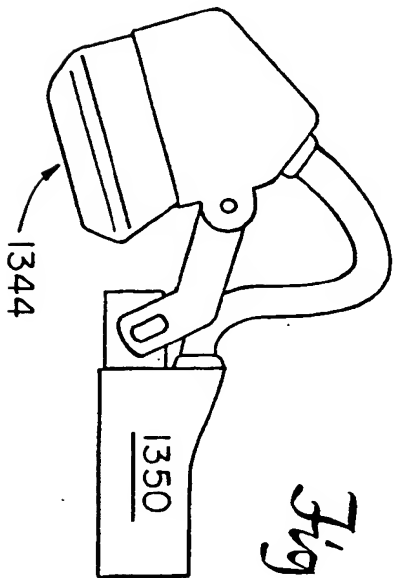


Fig. 57F

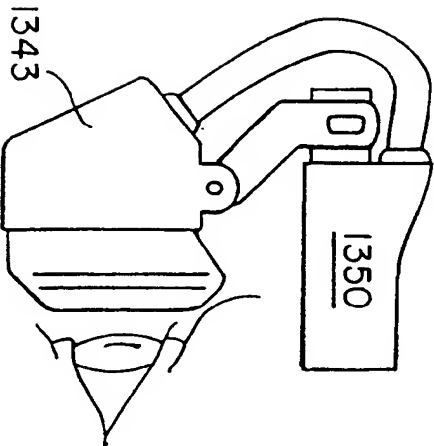
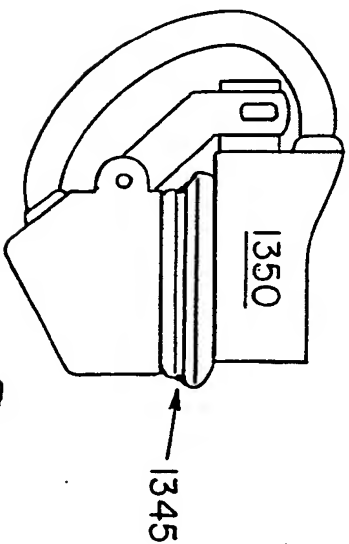


Fig. 57H



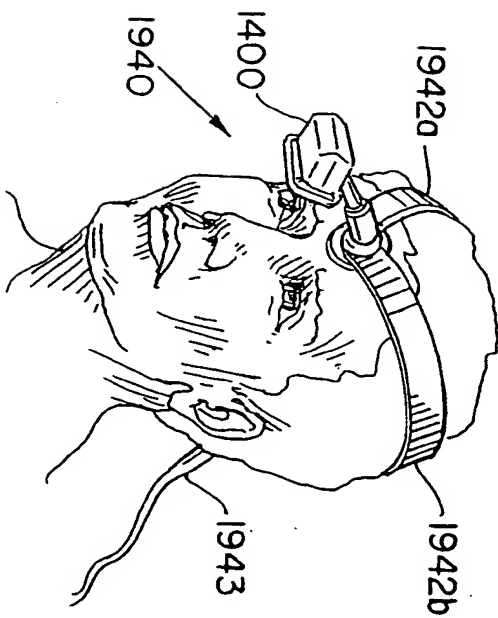


Fig. 58A

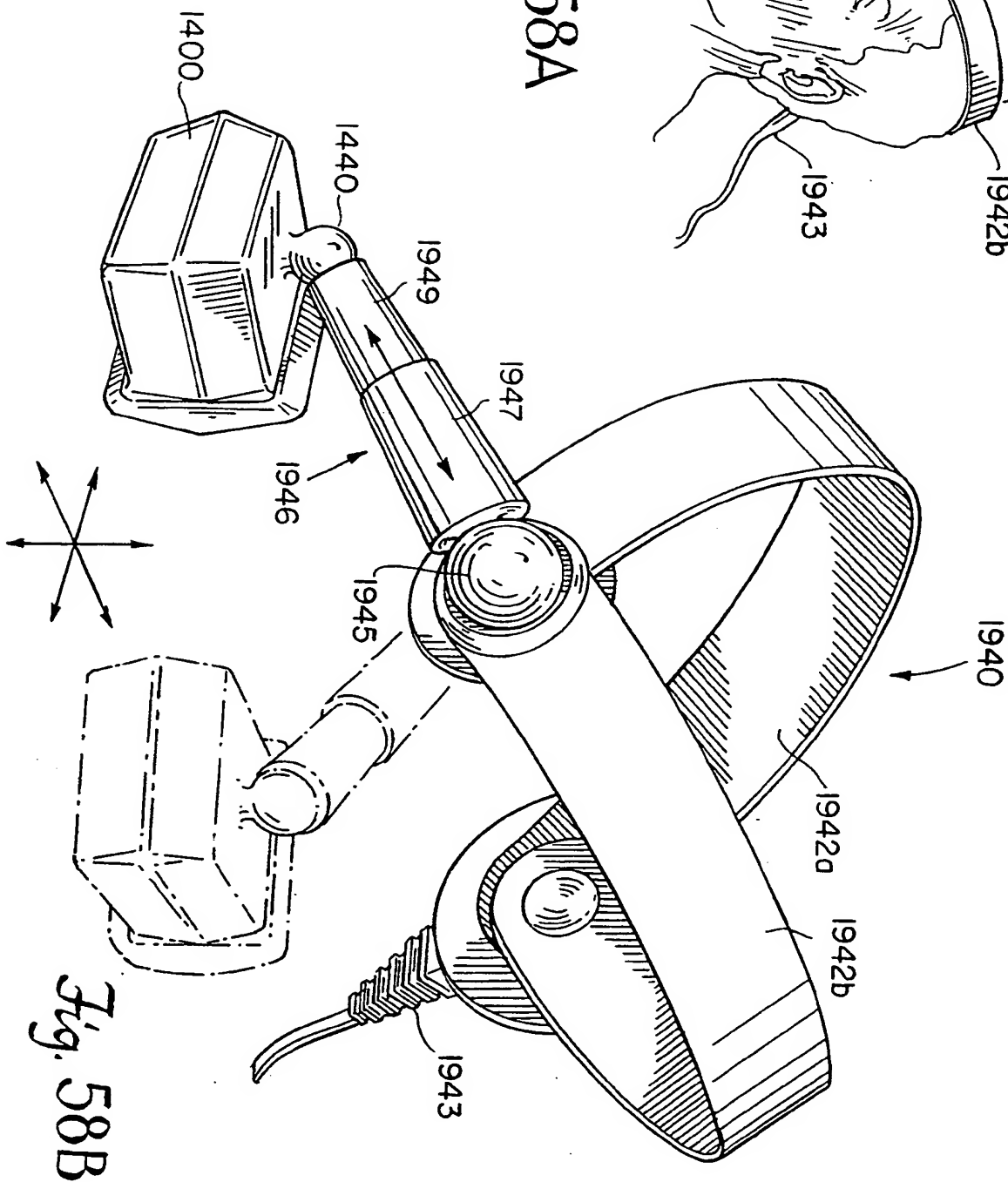


Fig. 58B

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Fig. 59E

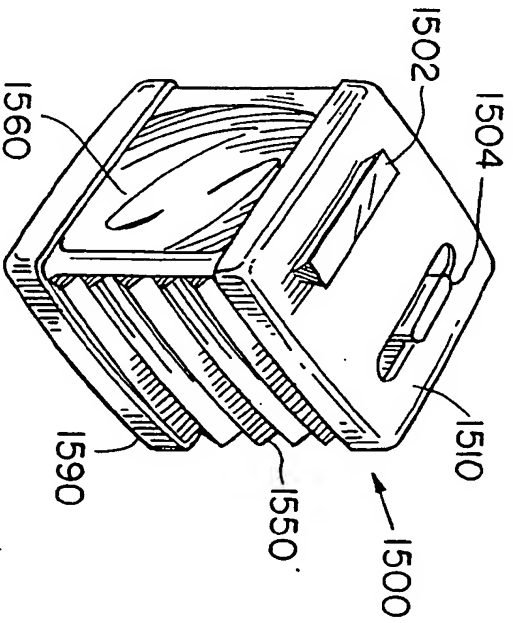
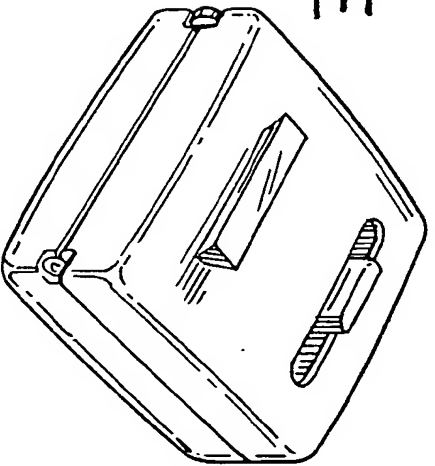


Fig. 59A

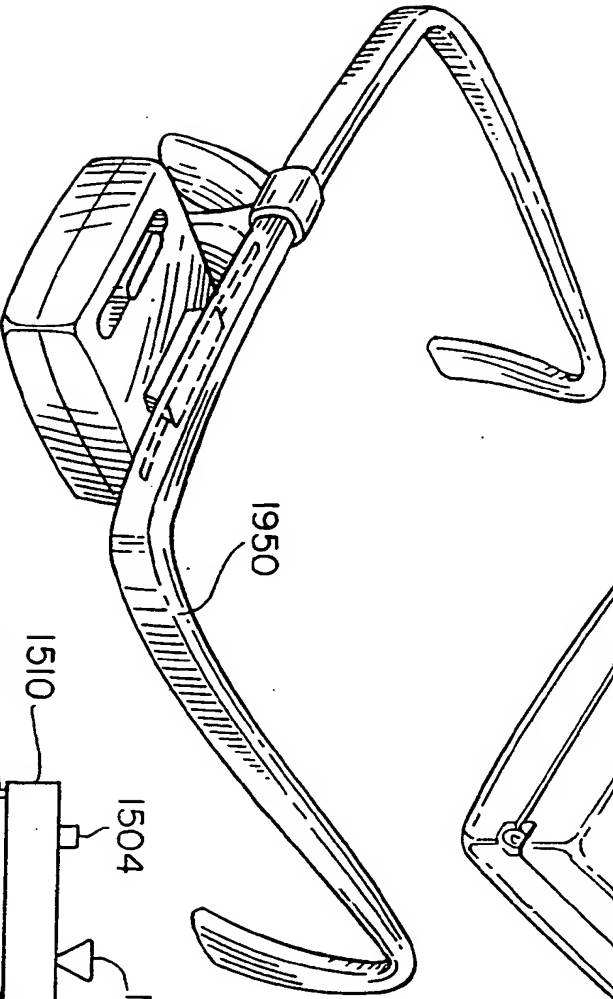


Fig. 59F

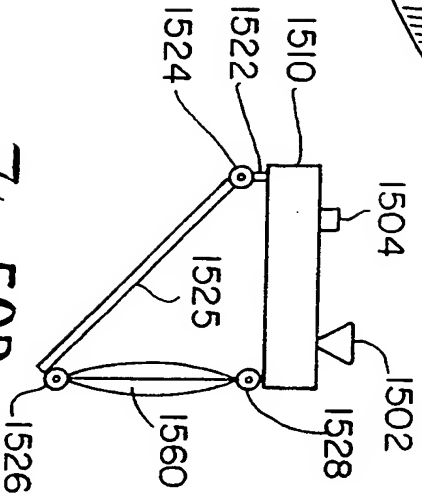


Fig. 59B

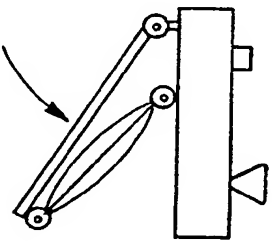


Fig. 59C

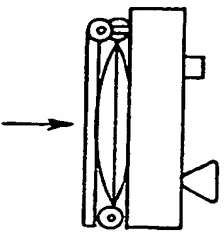


Fig. 59D

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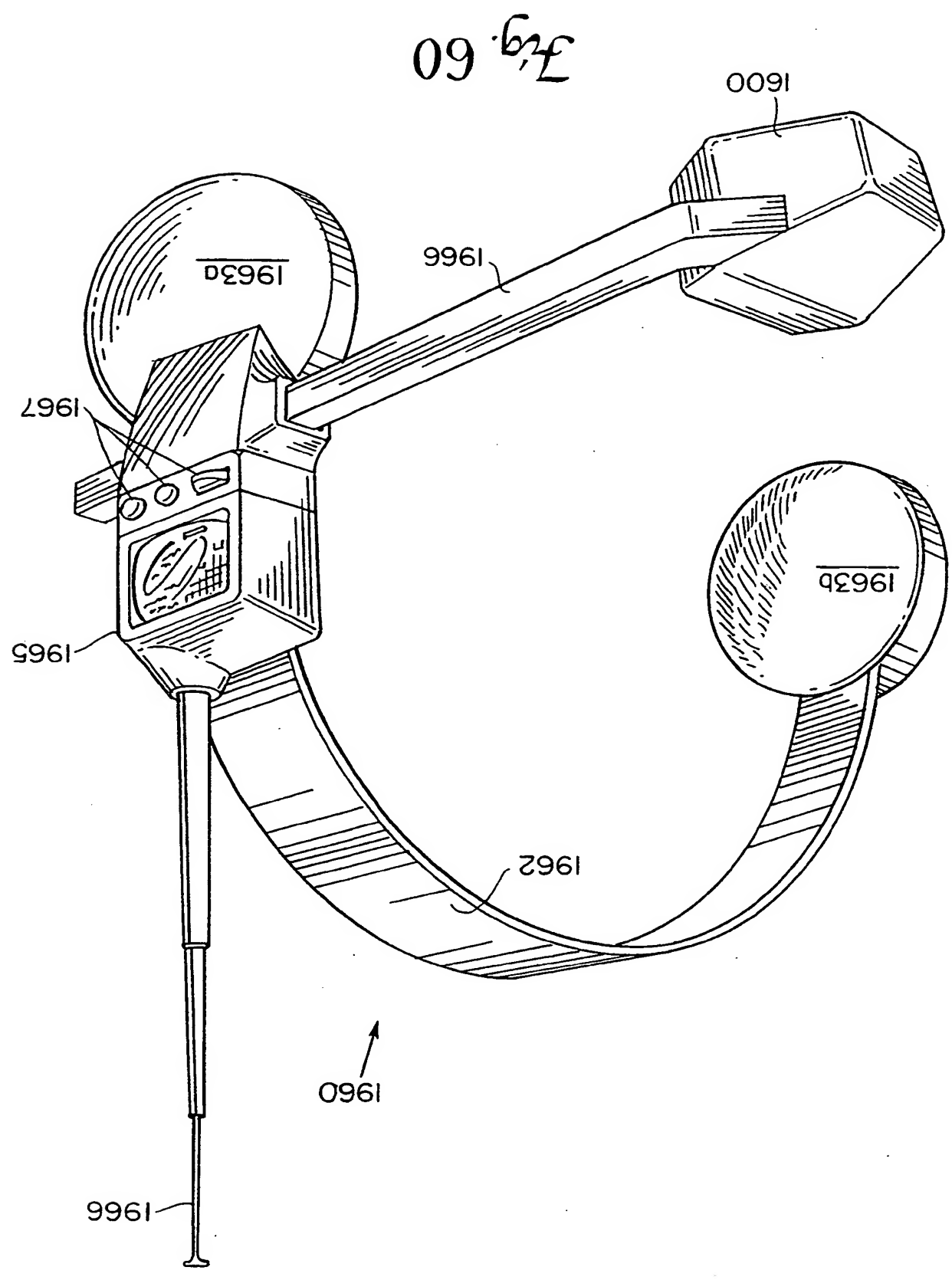


Fig. 60

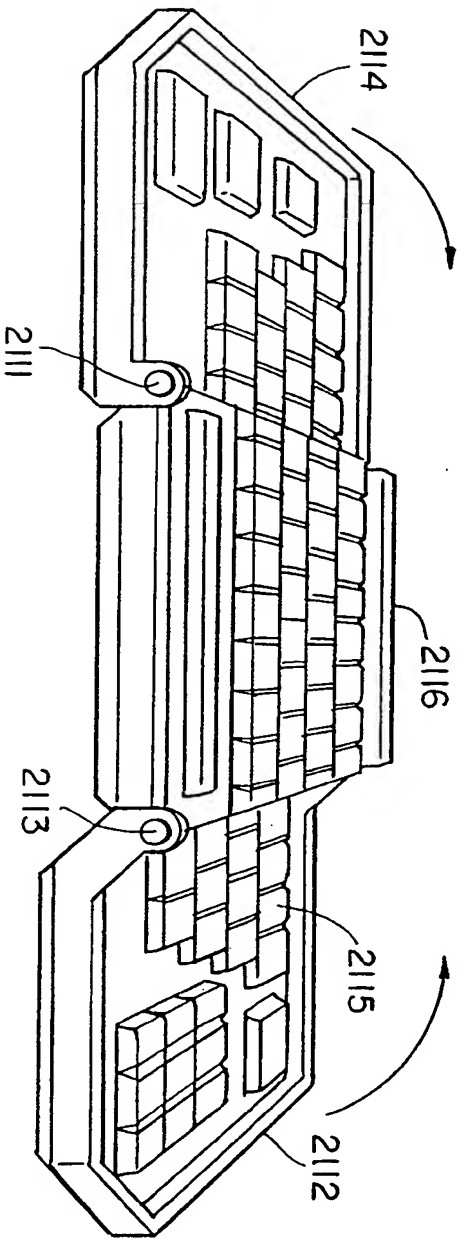


Fig. 61A

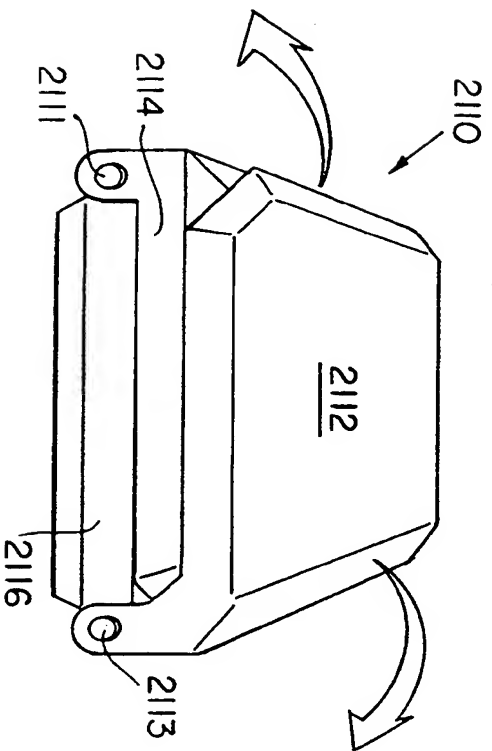


Fig. 61B

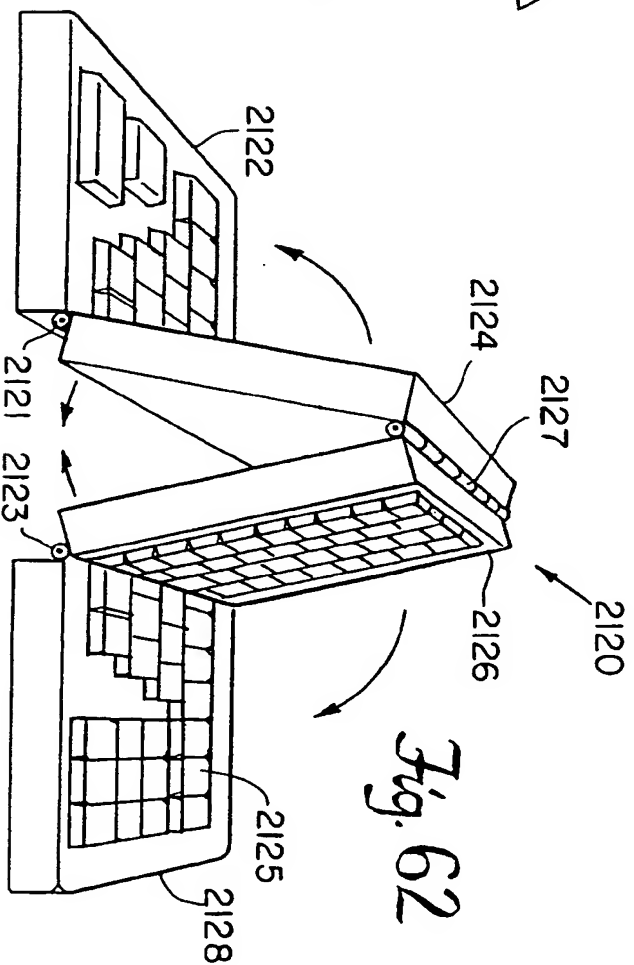


Fig. 62

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Fig. 63A

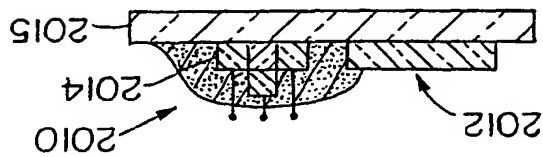


Fig. 63B

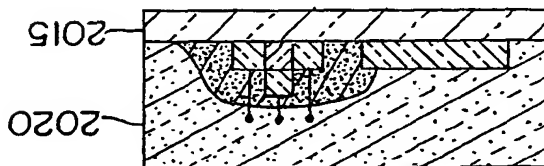


Fig. 63C

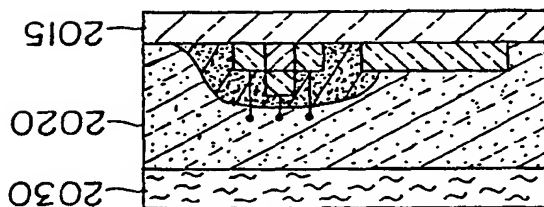


Fig. 63D

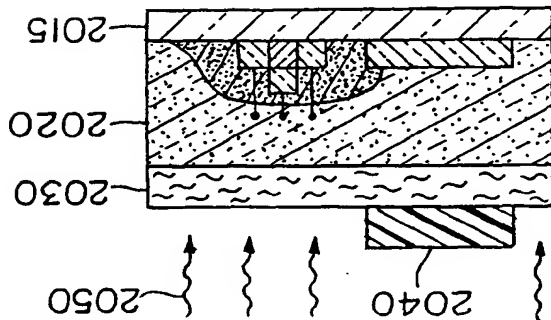
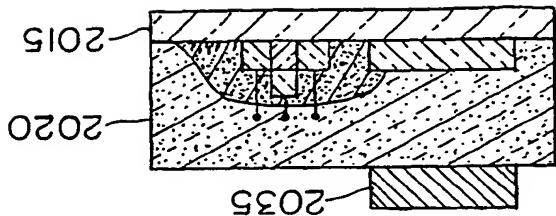


Fig. 63E



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Fig. 63F

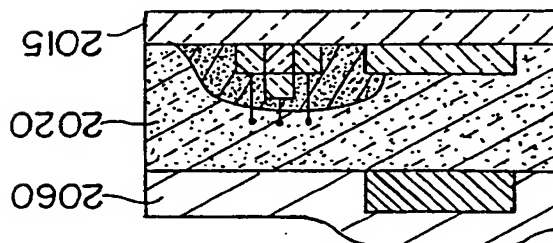


Fig. 63G

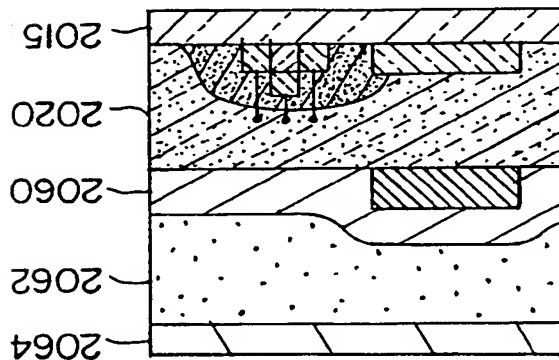
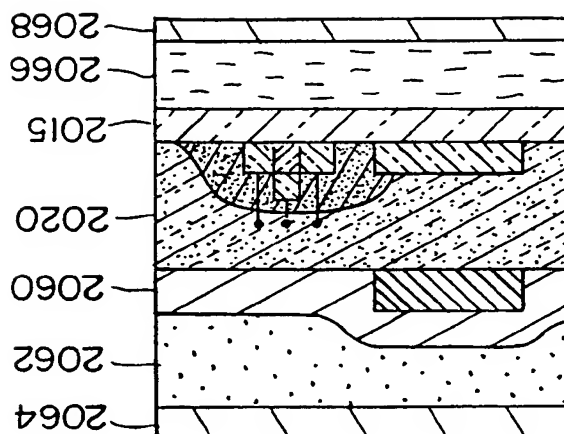


Fig. 63H



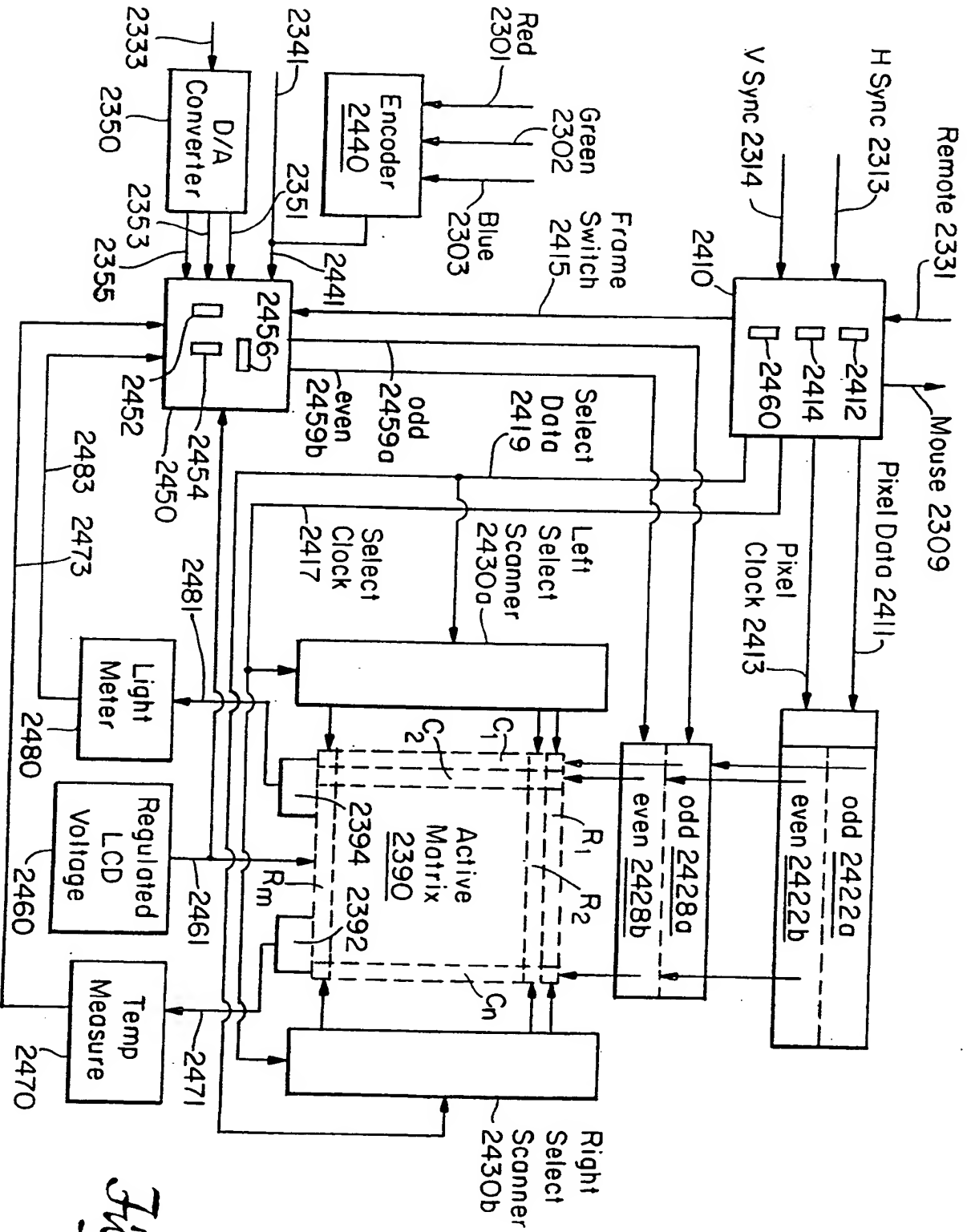
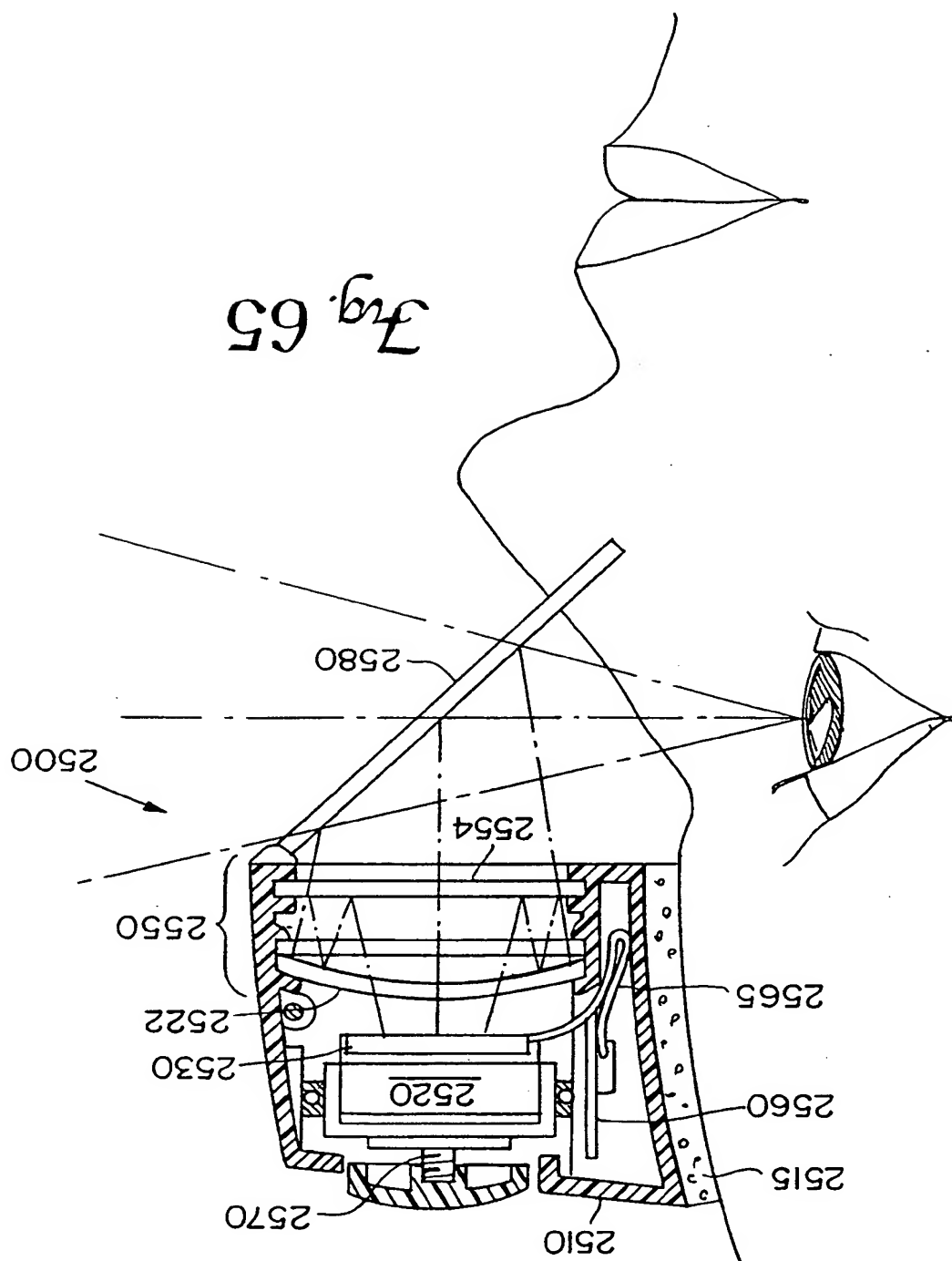
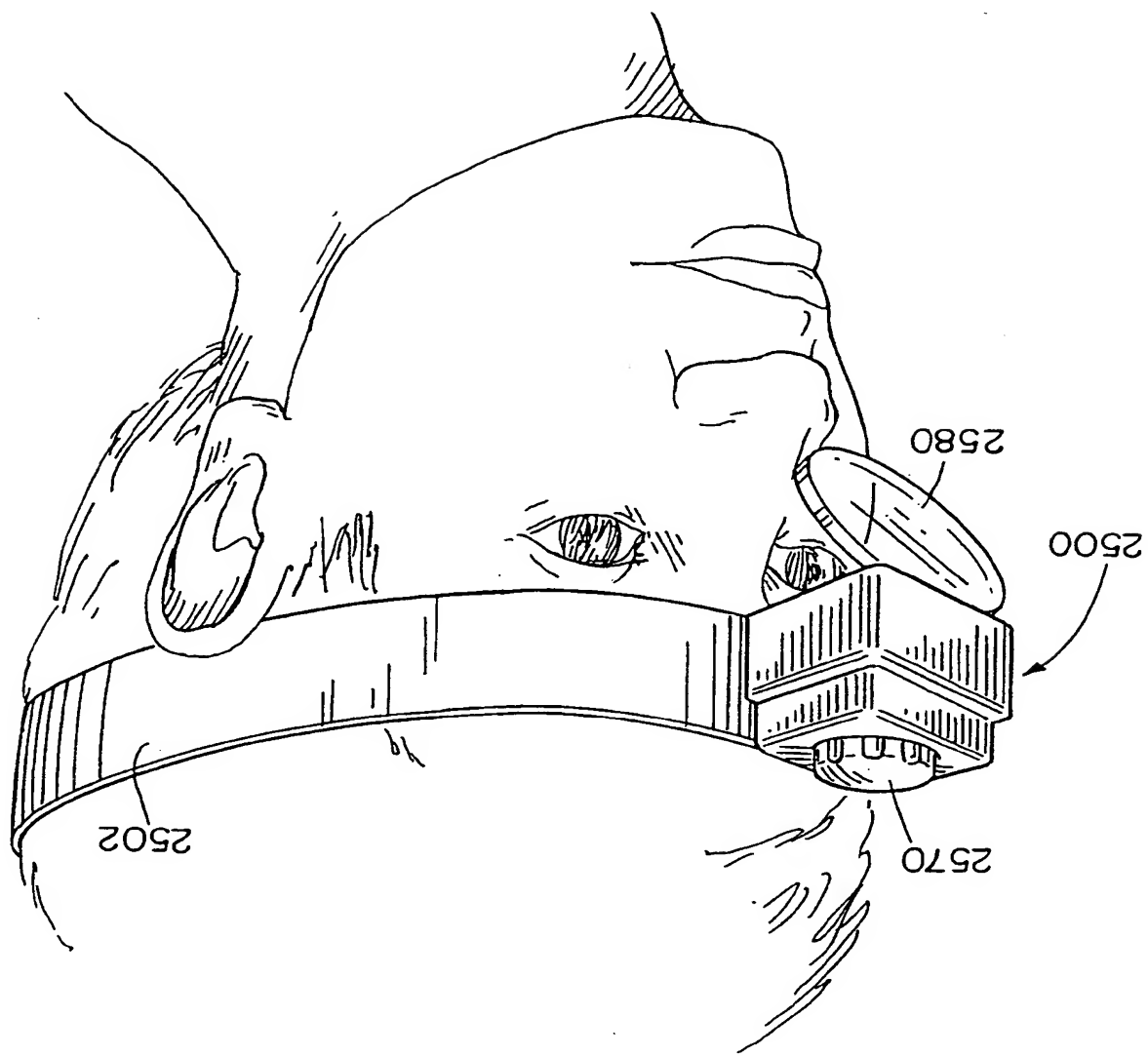


Fig. 64



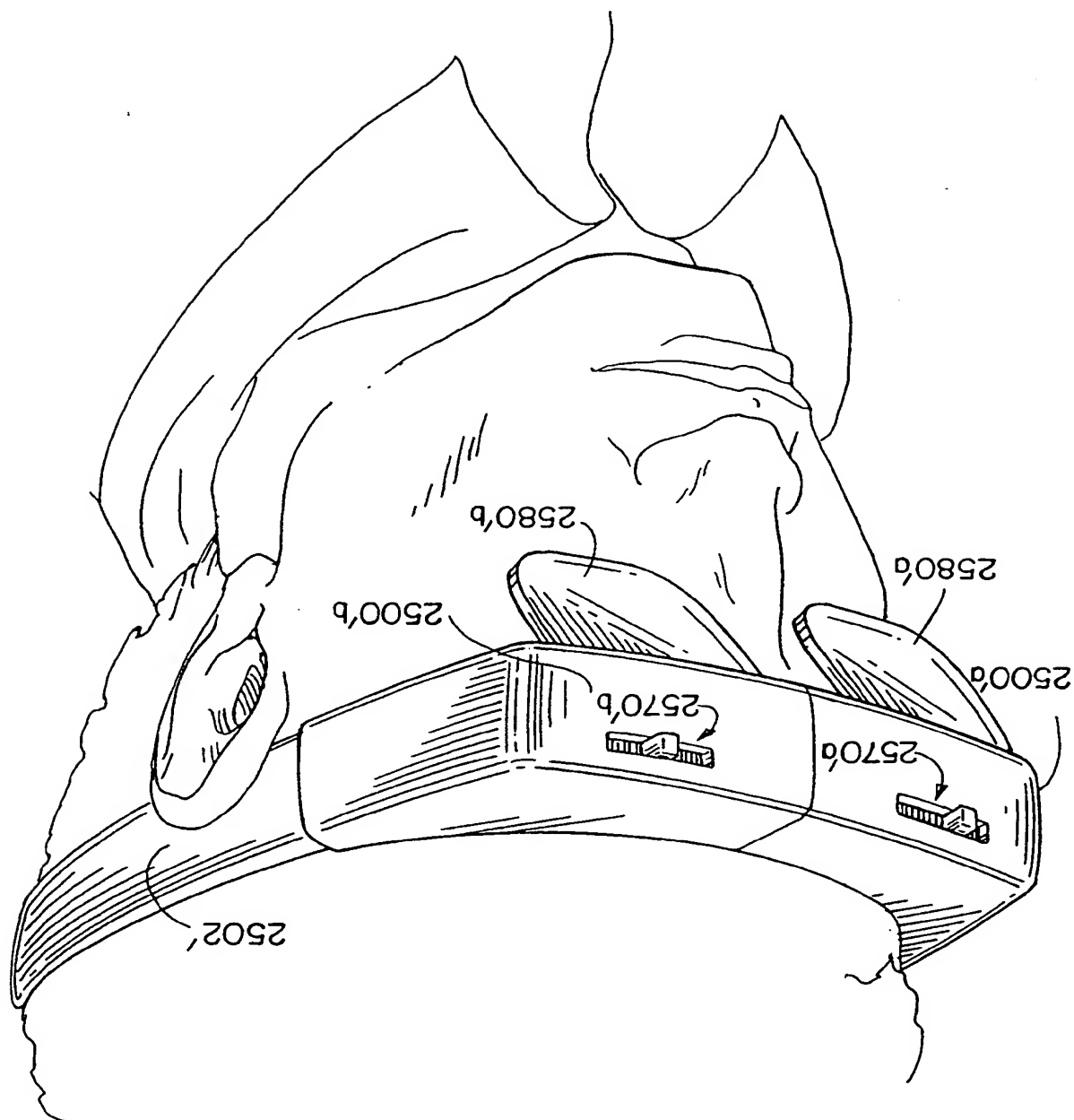
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Fig. 66



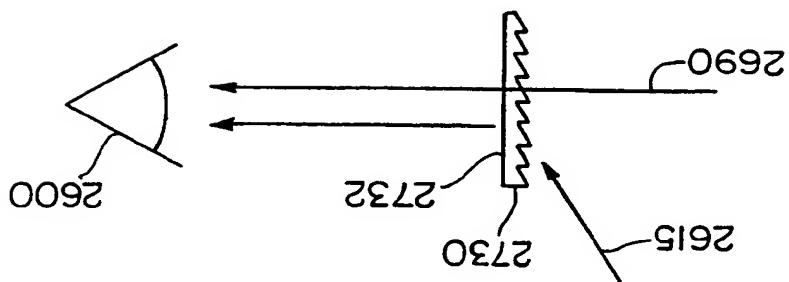
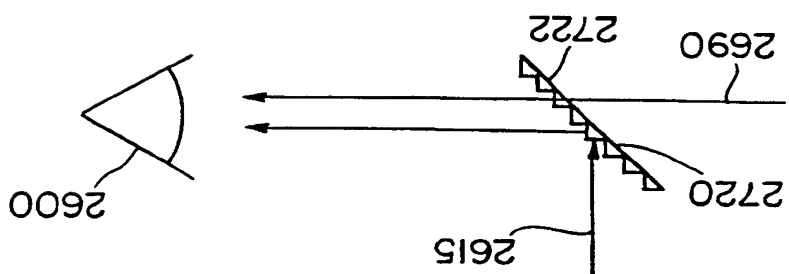
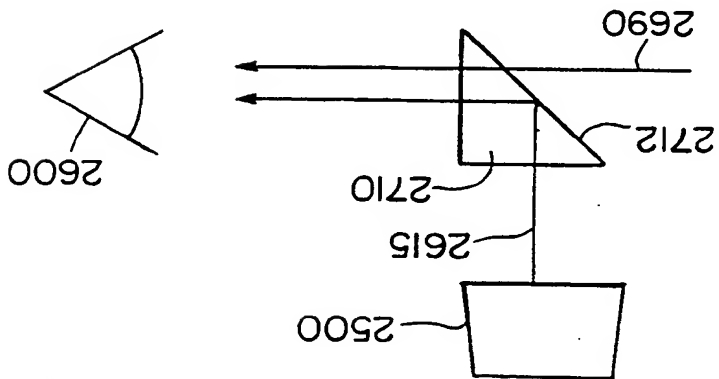
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Fig. 67



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Category	Citation of document, with indication, where appropriate, of the relevant passages
1. General	
2. Specific	
3. Other	

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